RESEARCH REPORT

GREENHOUSE GAS EMISSIONS FROM URBAN TRAVEL: TOOL FOR EVALUATING NEIGHBOURHOOD SUSTAINABILITY

HEALTHY HOUSING AND COMMUNITIES SERIES

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GREENHOUSE GAS EMISSIONS FROM URBAN TRAVEL: TOOL FOR EVALUATING NEIGHBOURHOOD SUSTAINABILITY

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EXECUTIVE SUMMARY

1 Introduction

As a result of the Kyoto Summit in December 1997, the federal government is developing strategies to reduce greenhouse gas (GHG) emissions in Canada. A key challenge to reaching this goal is urban transportation, which is a major and growing contributor to GHG emissions in Canada. This is largely due to increasing levels of private automobile use, together with declining rates of public transit use in most Canadian cities during the past decade.

Many studies demonstrate that there is a strong link between automobile ownership and use and the way communities are planned, designed and implemented. To date, little work has been done on quantifying the extent to which transportation energy consumption and emissions can be reduced as a result of alternative neighbourhood development scenarios.

Objectives

This study develops a model of GHG emissions from personal urban transportation given variations in neighbourhood characteristics, including community and housing design, socioeconomic make-up, and locational factors. The results provide valuable insight into how communities can be designed and planned to reduce GHG emissions from passenger travel in urban areas.

The main purpose of the study is to develop a user-friendly spreadsheet tool to make the mathematical model easy to use in evaluating development proposals in terms of GHG emissions. The user inputs data on the characteristics of the neighbourhood and the tool forecasts the annual per household GHG emissions from transportation. In this study, the results supplied by the tool are used in discussing the sustainability of nine neighbourhood scenarios that embody a wide range of contrasting locational and neighbourhood design characteristics.

2 Modelling Approach

Data on vehicle ownership, automobile vehicle-km of travel (VKT), and passenger-km of travel on public transit (PKT) per household in the Greater Toronto Area (GTA) were obtained from the 1996 Transportation Tomorrow Survey (TTS). This rich data set is based on a sample of 115,000 households (a 5% sample) in the GTA. The traffic zone level of aggregation was chosen for the basis of analysis, as this provides a convenient means for summarising travel data, and is also compatible with the need to make comparisons at the

neighbourhood level. The analysis was limited to traffic zones within the Toronto Census Metropolitan Area (CMA) and to traffic zones with a minimum number of responding households. The final data set for model calibration retained 795 traffic zones. Data on the individual variables that may have an effect on household travel behaviour were obtained from a variety of sources, including the TTS, Census data, and data derived from geographic information systems.

It was important initially to gain a thorough understanding of the individual potential explanatory variables. To this end, univariate analyses of the individual variable's impact on auto VKT per household were carried out. The primary modelling approach in this study was to develop separate sub-models of vehicle ownership, weekday auto VKT, and weekday transit PKT per household using multivariate regression analysis. Multivariate regression makes it possible to examine how a single dependent variable (e.g. VKT/household) is affected by the values of one or more independent variables.

3 Key Variables Influencing Auto Use and GHG Emissions

The results of the multivariate analysis reveal a number of insights about the effect of different neighbourhood characteristics on household vehicle ownership and auto and transit use. Overall, socioeconomic and locational variables tend to have stronger influence than neighbourhood design variables.

Socioeconomic Variables:

- The variable with the strongest influence on auto VKT was the number of vehicles per household.
- To a lesser extent, the number of people in the household is the second strongest influencer of VKT; the number of people per household is the strongest predictor of PKT, tied with local transit service.
- The average number of adults per household is the strongest predictor of auto ownership per household.
- Household employment income was the second most important indicator of household vehicle ownership whereas individual worker income seems to be a better predictor of auto VKT than household income.

Locational Variables:

- Distance to the Central Business District (CBD) has a strong influence in all three sub-models. This is the third explanatory

variable of auto VKT. The model parameters suggest that for every kilometre a household moves away from the CBD, weekday VKT per household decreases by approximately 1.0 km.

- An increase in the number of jobs within a 5-km radius of the neighbourhood centroid can greatly reduce auto VKT per household as can a high degree of land-use mixing (i.e. combining residential uses and jobs in an area).

- Increasing local transit vehicle service hours tends to reduce household vehicle ownership decisions and increase transit PKT per household. It was tied with number of people per household as the strongest predictor of PKT. Having close access to a rapid transit station slightly decreases auto ownership levels and VKT per household.

Neighbourhood Design Variables:

- An increase in housing density (the number of housing units within a 1-km radius of the neighbourhood centroid) moderately decreases vehicle ownership and increases transit travel.

- A high degree of mixing housing types in a neighbourhood can slightly reduce auto ownership while increasing the average size of a neighbourhood's housing units (in rooms/unit) can slightly increase auto ownership levels.

- Neighbourhoods with a curvilinear road layout type tend to have slightly increased auto ownership levels; those with a rural grid road type have slightly higher auto VKT levels, all else being equal.

- An increase in the number of intersections per road-km in a neighbourhood slightly reduces auto VKT, presumably because it improves connectivity for walking and cycling trips.

- Increasing neighbourhood employment moderately reduces household transit PKT.

- The presence of local shopping opportunities slightly reduces household auto ownership levels, and also reduces transit PKT and, as a result, indirectly reduces auto use.

- The presence of wide arterial roads either within the neighbourhood or on its periphery, slightly increases auto use.

- The presence of bike lanes and recreational paths slightly reduces auto use.

Appropriate factors were applied to predicted values of auto VKT and transit PKT to convert these values into annual GHG emissions per household. The final models, based on the multivariate regression approach, were incorporated into an **easy-to-use Microsoft Excel 7.0 based spreadsheet tool**. All of the variables described above can be manipulated by a user of the tool to test a variety of development proposals in terms of GHG emissions from personal travel. The tool is capable of establishing the relative difference between two or more neighbourhoods in any large metropolitan area, although the absolute GHG estimates may not be exact. Appendix A of this report has a user's guide for the spreadsheet tool.

4 Neighbourhood and Urban Context Scenarios

Nine contrasting neighbourhood scenarios were subjected to analysis using the model, executed within the spreadsheet tool. These nine neighbourhoods are combinations of three neighbourhood designs and three urban contexts. The three urban context scenarios generally correspond well to the Inner Area, Inner Suburbs, and Outer Suburbs of the Toronto Census Metropolitan Area. These are located 5 km, 10 km, and 30 km from the Central Business District, respectively, and have varying access to employment and transit.

The neighbourhood design concepts are as follows:

- **Neighbourhood 1: Conventional Suburban-Type Development**—This neighbourhood concept reflects the characteristics of modern suburban developments, with typical low-density single-use residential developments. Street patterns generally consist of curves and cul-de-sacs extending out to wide auto-oriented arterial roadways.

- **Neighbourhood 2: Medium-Density Development**—This neighbourhood concept tends to have a mix of single detached houses on medium-sized lots, low rise townhouses and mid-rise residential apartment buildings. Such neighbourhoods typically have a higher number of persons than jobs, but still have significant opportunities for self-containment in terms of local employment. The road layout would mainly be curvilinear, but with some continuity and connectivity for transit vehicles and pedestrians.

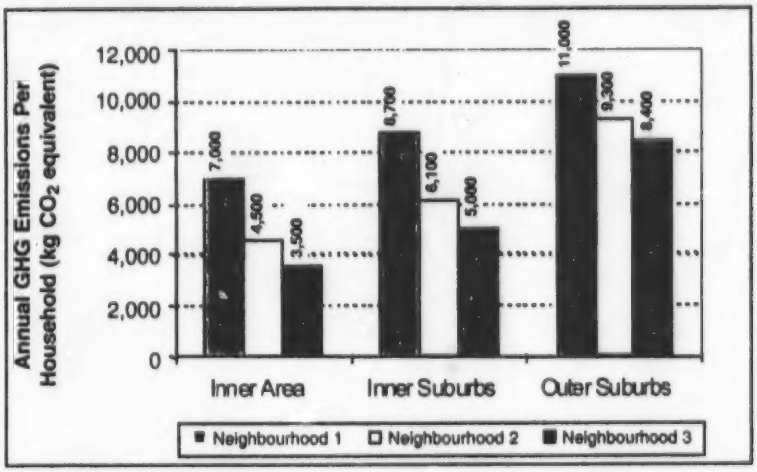
- **Neighbourhood 3: Neo-Traditional Development**—This neighbourhood concept represents a return to communities that are more "friendly" to pedestrians, bicyclists, and transit users. The road layout type is generally a grid pattern of closely-spaced streets with full accessibility to adjacent arterials. Such neighbourhoods have a mix of housing typologies including apartment buildings and closely spaced housing units. There

is a much greater presence of non-residential uses (grocery stores, retail shops, schools and employment complexes) in this neighbourhood concept than in the first two neighbourhoods.

The following chart shows graphically the annual GHG emissions for the nine different neighbourhoods as predicted by the model, making it easy to see that both the urban context and the neighbourhood design context have a significant effect on GHG emissions from urban travel. The single-use, dispersed neighbourhood located far from the CBD produces about three times more annual emissions per household than the mixed-use, compact neighbourhood near the CBD.

It is valuable to note that the neighbourhood's location has a stronger influence on auto use than the neighbourhood design variables. Changing the neighbourhood context from the Outer Suburbs to the Inner Area decreases GHG emissions by 36 to 60% for the various neighbourhoods. Whereas keeping the urban context the same and changing the neighbourhood design from conventional suburban to a compact, mixed-use, pedestrian-oriented design decreases GHG emissions 24 to 50%. Neighbourhoods with neo-traditional neighbourhood designs located in the Outer Suburbs produce more GHGs than the neighbourhood with single-use suburban-type design located in the Inner Area. The former neighbourhood generates 20% more annual GHG emissions from travel than the latter.

Figure E1:
Neighbourhood Scenarios' Annual GHG Travel Emissions per Household



5 Conclusions

Key Findings

This study resulted in the development of a spreadsheet tool that enables the user to estimate and compare various neighbourhood scenarios for GHGs from urban travel. It is based on a model that is able to explain a substantial amount of the interaction between neighbourhood characteristics and vehicle use. The R^2 values for the auto VKT and auto ownership models are 0.84 and 0.88, respectively, which bodes well for the reliability of the models. Whereas the R^2 for the transit model is only a moderate 0.329, which means that the transit-use model is less reliable.

The results of the evaluation of the nine neighbourhood scenarios using the model developed in this study suggest that the "macro" urban structure is more important than the "micro" neighbourhood design in reducing GHG emissions from auto and transit travel by neighbourhood residents. That is, infill development is more effective than greenfield development in moderating the growth of GHG emissions, even if the new greenfield neighbourhood is neo-traditional rather than typical suburban in design. However, neighbourhood design is also a significant determinant of GHG emissions and can go a long way in improving the sustainability of neighbourhoods in the outer regions of urban areas.

The spreadsheet tool produced by this study provides a useful instrument for planners and developers in comparing the GHG emissions of different neighbourhood scenarios. It enables them to compare the implications of both local neighbourhood design and the broader-scale urban structure considerations of infill versus greenfield development.

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1. INTRODUCTION

As a result of the Kyoto Summit in December 1997, the federal government is developing strategies to enable Canada to reach its target of reducing Greenhouse Gas (GHG) emissions by six per cent from 1990 levels by between 2008 and 2012. Urban transportation is a major and growing contributor to GHG emissions in Canada, largely because of increasing levels of private automobile use. Many studies, including current and earlier work of Canada Mortgage and Housing Corporation (CMHC), demonstrate a strong link between automobile ownership and use, and the way communities are planned, designed and implemented. Less work has been done, to date, on modelling the transportation patterns and reductions in transportation energy consumption and emissions that would result from alternative development scenarios.

The purpose of this study is to develop a quantitative tool to evaluate development proposals in terms of GHG emissions from urban transportation. The study compares the GHG emissions from personal urban transportation given variations in community planning and design variables such as density and land use mix. This information will provide valuable insight into how communities can be designed and planned to reduce GHG remissions from private automobile use. The tool developed as part of this study will help users compare and estimate GHG emission levels from a range of development proposals with different urban form and locational characteristics.

This report provides a summary of the analysis and results as well as a user guide for the evaluation spreadsheet tool.

2. DEVELOPMENT OF THE APPROACH

A literature review helped to identify approaches used in previous studies that examine how urban design impacts private vehicle use. A study recently conducted for CMHC, *The Impact of Urban Form and Travel Accessibility on Private Vehicle Use: Literature Review* provided insight into the range of methods that have been used and helped in selecting the most appropriate ones for developing the model and evaluation tool.

The model, on which the neighbourhood evaluation tool is based, best replicates the empirical relationships among variables. Because the intent of this exercise is to develop a "quantitative tool," multivariate regression analysis is the most suitable method of analysis as it produces an equation that can be used to quantify the relationships mathematically and can reflect the cumulative effect of several factors influencing travel behaviour.

There are many advantages to conducting such an analysis at the household level since this is the level where most decisions about travel and location are made. For example, a decision to own a certain number of vehicles is normally made at the household level and, as confirmed in this study, vehicle ownership is a key indicator of auto use. On the other hand, most neighbourhood variables, such as density and land use mix, are available at the zonal level only.

The analysis presented in this study is based on zonal data. Since the focus is on neighbourhoods and their performance, it was felt that a zone-based approach was preferable. It is important, however, to recognize that this approach could mask some of the true behavioural relationships that would otherwise be apparent at the household level.

For this analysis, we considered all trip purpose categories together, making the assumption that trips for different purposes can be modelled in terms of the same variables.

To quantify the linkages between urban form and total GHG produced in daily travel, it is necessary to quantify both automobile use and transit use. Since the focus is on GHG emissions, it is appropriate to look at vehicle-kilometres of travel (VKT) as opposed to the other indicators such as modal shares. In the same way, transit use will be measured as passenger-kilometres of travel (PKT).

In most cases, indicator variables are normalized using a denominator such as persons, households or neighbourhoods/cities. The specific denominator depends on the level of aggregation being used. For this study, we normalized VKT and PKT by the number of households in each zone so the dependent variables are VKT/household and PKT/household.

Based on other studies, auto use depends on many factors, including those pertaining to urban form. There is a general consensus that the following variables related to urban form have some influence on auto usage patterns.

- *Population and employment densities*. Many studies show that densities affect travel behaviour variables such as auto ownership and use. However, the influence of density can be overestimated in studies that do not account for other variables, such as household income, that are correlated to density.

- *Land use mix*. Mixed land use results in more "intervening opportunities" and shorter trip lengths, which favour more walking, cycling and transit use.

- *Transit accessibility*. Higher transit service and accessibility levels are correlated with higher transit use, but transit service also depends on other factors such as density.

- *Socioeconomic variables*. In particular, auto use is correlated with auto ownership and, in

turn, auto ownership has been shown to depend on other socioeconomic variables (e.g., income and household size).

- *Regional accessibility*. Research has found that the ease of access to regional jobs and activities by transit influences modal choice.

Summary and Model Directions

Based on the literature review, developing a model based on a multivariate regression approach that relates a dependent variable, such as auto use per household, to a number of explanatory variables (also referred to as independent variables) is most appropriate. The major methodological issues identified from the literature review are:

- isolating the impacts of neighbourhood design from the impacts of locational factors;
- deciding on the most appropriate indicator variables (i.e., dependent variables); and
- determining how each independent variable affects the dependent variables, and ensuring that the independent variables are properly specified in the regression equation to reduce covariance between them.

In addition, with the goal of developing a user-friendly tool to evaluate neighbourhood sustainability, it is desirable to develop a model in which the explanatory variables to be specified are those the user is able to control or predict to some degree of certainty. Because auto ownership itself may be predicted from some of the same independent variables for vehicular and transit travel, it was decided to model this variable separately, then use the result in predicting travel behaviour. This approach, which is described in Chapter 4, is referred to as simultaneous regression.

3. PRELIMINARY ANALYSIS OF VARIABLES

This section describes the sample data set and develops an initial understanding, through a single-variable analysis approach, of the urban form and neighbourhood design factors that potentially influence GHG emissions. Detailed descriptions of the variables used are provided, as well as a discussion of how each variable is expected to contribute to help predict GHG emissions in the final multivariable regression model, such as the variable's expected predictive strength or its most-suitable functional form (e.g., linear or logarithmic).

It is stressed that the results of the multivariable regression analysis described in Chapter 4 may be different from those emerging from this initial analysis. The differences between the results of these analyses emphasize the strengths of the multivariate approach in isolating the contributions of the individual predictor variables to household travel. **Multivariate regression ultimately provided the basis for including the given variable in the final model.**

Because it is assumed that GHG emissions primarily depend on the amount of travel by the auto mode, for the analysis in this chapter, only the relationships between the explanatory variables and automobile use are described in detail. It is recognized that transit vehicles also generate GHG emissions, albeit to a much lesser extent per person carried (at reasonable load factors such as experienced in Greater Toronto's built-up areas). A brief discussion of the variables impacting transit PKT is provided at the end of this chapter with additional information in the following chapter describing the actual model development. A description of how travel estimates are converted into GHG emissions is also provided in Chapter 4.

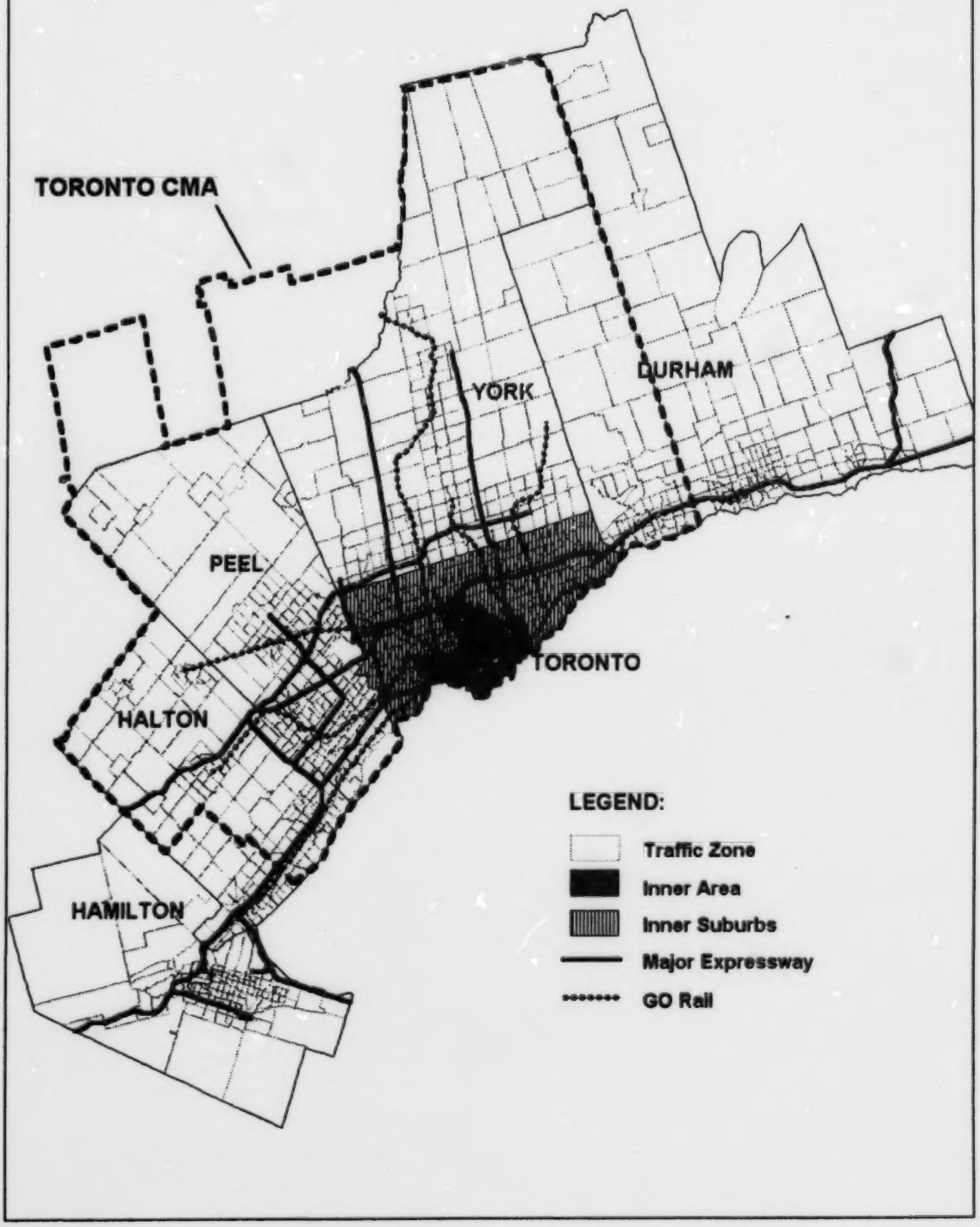
Description of Data Set and Geographical Context

The primary source of data on travel patterns and automobile VKT in the Greater Toronto Area (GTA) is the 1996 Transportation Tomorrow Survey (TTS). One of the largest surveys of its kind in North America, the 1996 TTS is based on a sample of 115,000 households (a five per cent sample) in the GTA. Data from the TTS theoretically are available at any level of aggregation. For this study, the traffic zone level of aggregation was chosen for the basis of analysis. Traffic zones provide a convenient means for summarizing travel data and are also compatible with the need to make comparisons at the neighbourhood level. Within the GTA (including Hamilton-Wentworth) there are 1,404 traffic zones. The Toronto Census Metropolitan Area (CMA), which is the focus of this study, contains some 832 census tracts or 1,036 traffic zones. Initially, we considered using the whole GTA, but it was found that zones in other CMAs (Oshawa and Hamilton) seemed not to fit certain relational forms in the same way as zones in the Toronto CMA alone. This, in large part, can be explained by the self-containment of the CMAs. Hence, only zones in the Toronto CMA were included. On average, the zones are about 6 km^2 in size, although zones in built-up areas are generally between 1 and 2 km^2. The average number of households per traffic zone is 1,290, but the range is from 0 to 10,000.

Exhibit 1 provides a geographical context for the study by showing the traffic zones in the GTA in relation to political boundaries, physical infrastructure and the boundary of the Toronto CMA.

It also shows the boundaries of the "inner area" and the "inner suburbs." This inner area is slightly larger than the old City of Toronto. The inner suburbs refer to the area within the City of Toronto (formerly Metropolitan Toronto) but excluding the inner area. The remaining areas within the CMA, but outside the City of Toronto, are referred to as the outer suburbs. These three areas are for description purposes only and are not used in the final model specification.

Exhibit 1
Geographic Context



Of the 1,036 traffic zones in the Toronto CMA, some actually had very few respondents, resulting in a large variance in the travel data related to these zones. Therefore, data from zones that had fewer than three responding households were not included in the analysis. This reduced the sample by 231 traffic zones. A further 10 zones were removed from the study because they were obvious outliers; inspection of these zones noted that all but one had fewer than 10 responding households. In the end, data from 795 traffic zones were retained for analysis and model development.[1]

Defining the Dependent Variable

As described above, all the travel data used in this study are developed at the traffic zone level. Since the traffic zones vary in land area, population and employment, it is necessary to develop a standardized measure of VKT (i.e., the dependent variable).

The method chosen to develop the auto VKT portion of the dependent variable is based on a trip chaining approach in which the daily travel made by an individual is treated as a single chain. For example, one might travel from home to work, from work to the gym and from the gym to home. Each of these individual trip segments and the mode by which they are made would depend on the characteristics of the trip maker, including where he/she lives. It is reasonable then to assign all the VKT made by an individual to that individual's place of residence. The sum of the VKT made by all individuals living in a particular zone would represent the total "travel effort" for that zone. Travel effort is normalized by dividing by the number of households in the zone.

In the initial stages of this study, other methods of normalizing the dependent variable, such as using VKT/capita, were explored but, in all cases, VKT/household provided a much better "fit" in the regression analysis. As discussed later, because there are differences in household size by location, it is necessary to incorporate household size into the regression equation as an independent variable when the dependent variable is expressed on a household basis.

Explanatory Variables

In the sections below, auto VKT per household is used as the primary dependent variable for exploring the influences of various factors independently (through univariate regression) on GHG emissions. These factors can generally fit into one of three categories: socioeconomic variables, locational (urban-context) characteristics and neighbourhood characteristics.

A notable weakness of univariate analysis is that what may appear to be the effect of one variable on the dependent variable can be the effect of other variables correlated with it. Because of this weakness, this chapter focusses on the key variables that emerged from a more extensive analysis involving multivariate regression. It is useful first to examine the statistical estimation power of the independent variables considered for inclusion in the model. This initial understanding of how the separate variables seem to affect the dependent variables helps to describe why the variable was initially considered, although because of covariance between the variables, it should be remembered that this provides only a rough indication of how the variables will perform. Individual explanatory variables can perform quite differently in multivariate regression analysis than in univariate regressions. An example is land use mix, which did not seem to be a particularly strong predictor in the univariate analysis, but turned out to be a strong explanatory variable in the multivariate auto VKT model.

Socioeconomic variables and VKT

This section discusses how various socioeconomic variables may influence VKT. In the development of neighbourhood scenarios (Chapter 5), socioeconomic variables are held constant, although they can be varied by users of the spreadsheet tool if information on the

sizes, incomes and life-stage characteristics of the households for whom a development may be marketed is known.

Household Structure, Age Composition and Size

The structure and size of a household can influence travel behaviour and travel patterns. However, as household structures become more complex, so do their travel patterns. In recent years, there has been a trend toward fewer people per household as well as a greater proportion of multiple-worker households (Shalaby, 1998). With two workers per household, it is generally more difficult to optimize residential and work locations.

Although it would be difficult to control household structure in the development of a neighbourhood, it is nevertheless important to gain an understanding of the relationships between household structure and travel activity, at least in terms of household size.

Not surprisingly, household size affects auto VKT. The apparent effect of household size is exaggerated by locational factors. For example, in the range of roughly 2.5 to 3.5 persons per household, there is much greater auto VKT for households of the same size in the outer suburbs than in the inner suburbs, whose levels are themselves greater than in the inner area. When plotting VKT against average household size (persons/household), the R^2 was just over 0.2, which indicates only a slight positive correlation.[2]

It is widely recognized that both the amount and mode of travel vary according to an individual's stage in life. Generally, people 35 to 55 years of age tend to make the most trips by auto when expressed on a per capita basis (IBI Group, 1997). This same age category of people also tends to make a smaller proportion of trips by transit compared to other age categories. Transit use tends to be higher by younger adults (e.g., ages 18 to 24).

When plotting auto VKT per person vs. the percentage of residents in a zone who are under 16 years of age, a very weak trend of increasing VKT per person and age structure is revealed. However, within the inner and outer suburbs, a slight trend toward decreasing VKT with an increasing percentage of young people can be noticed instead. Any impacts of age distribution appear overridden by numerous other household and location factors related to age distribution.

Hence, where age becomes important in this analysis is in terms of its spatial distribution. For example, younger families may tend to locate in the outer suburbs of the GTA where housing is cheaper, thereby having an influence on the spatial patterns of VKT/household. The TTS data suggest this is, in fact, the case.

The data on age distribution can be used together with household size information to determine the average number of adults (residents over 16 years of age) per household. A value of more than two for this variable reflects the presence of families with older children still at home. This variable is expected to explain some household travel decisions better than the variable total persons per household because the decisions are made primarily only by the adults and possible drivers in the household. For example, the best fit linear regression line for household auto ownership vs. adults/household had a moderate R^2 value of 0.381, and an R^2 of 0.18 in predicting auto VKT/household. (A natural log linear regression line provided a marginally better fit in predicting auto ownership, with an R^2 of 0.42; the linear form is retained in the multivariate model for simplicity.)

Average Income

In general, one expects that higher incomes would lead to a greater ability to purchase and use automobiles and, therefore, a greater propensity to travel by car. Two measures of income were considered in predicting travel behaviour: average employment income (averaged over all workers only, both full time and part time) and average household employment income. Data on average employment income and labour force participation rates by census tract are available

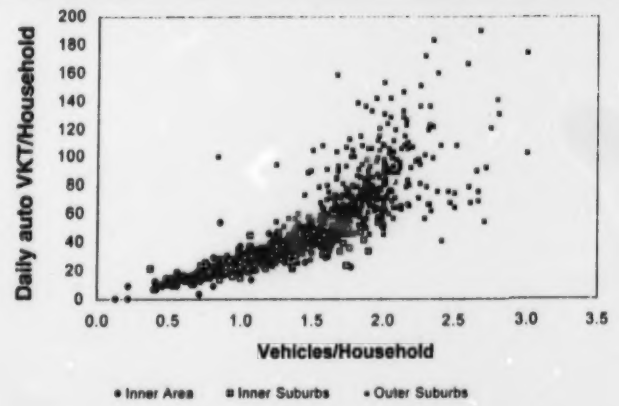
from the 1996 Census; average household employment income can be calculated based on these statistics.[3]

Based on data for this study, there is a slight positive correlation between VKT/household and average employment income. On a CMA-wide basis, households in the zones in the middle-income categories tend to have the highest VKT per household while zones with lower and higher average employment incomes yield less VKT per household. Although the use of average income as an explanatory variable on its own seems limited, the cumulative impact of income levels on auto VKT is shown to be more apparent when their effects can be isolated from locational impacts, as is the case in multiple regression.

Auto Ownership

The availability of automobiles is undoubtedly a key factor in travel decisions. Exhibit 2 provides some insight into the correlation between auto ownership and auto VKT/household. As shown, the relationship is very strong. It is important to recognize that most of the zones with higher auto ownership are located in the outer areas of the GTA while most of the zones with low auto ownership are located in the inner areas. However, within each of these locational categories, there is a clear trend toward increasing auto VKT with increasing auto ownership levels. Overall, an exponential relationship seems to fit the data better than does a linear relationship (R^2 of 0.72 vs. R^2 of 0.61).

Exhibit 2
Auto VKT/Household vs. Auto Ownership



Auto ownership is influenced by a number of socioeconomic and locational variables. A recent study by Schimek (1996) examining the impacts of household vehicle ownership concluded that "the most important statistical determinants of the number of vehicles per household are household income, household size, and the number of workers per household." In another study by Hunt Analytics Inc. (1999), household size, auto-accessibility in the home zone and household income were found to be the strongest influences on auto ownership.

Exhibit 3
Auto Ownership Trends vs. Socioeconomic Factors and Neighbourhood Attributes

	Inner area	Inner suburbs	Outer suburbs
Automobiles/household	0.60	1.21	1.72
Percentage of households with no vehicle	51%	25%	6%
Percentage of pop with drivers licence	67%	80%	86%
Average income	$33,397	$31,993	$34,350
Percentage of households living in single detached houses	3%	35%	62%

Exhibit 3 (from the TTS data) suggests there are differences in auto ownership and other factors by location. The relationships among these variables are explored in Chapter 4 using multivariate regression.

An important consideration in the model development is to restrict the input variables used, as much as possible, to those a planner or developer could control directly. As such, vehicle ownership is treated as an intermediate dependent variable in the model, itself a function of other socioeconomic factors, location and neighbourhood design.

Also, due to the close correlation between auto ownership and VKT, and the strong influence of neighbourhood and socioeconomic factors on both variables, both dependent variables were regressed simultaneously in the multivariate regression. A simultaneous regression approach has been adopted in this study, as described further in Chapter 4.

Locational characteristics

In this study, locational characteristics include those characteristics of a neighbourhood that define where it is located within the urban area. A neighbourhood's location spatially in the larger urban area influences other neighbourhood locational characteristics such as proximity to transit services, to jobs and to major activities.

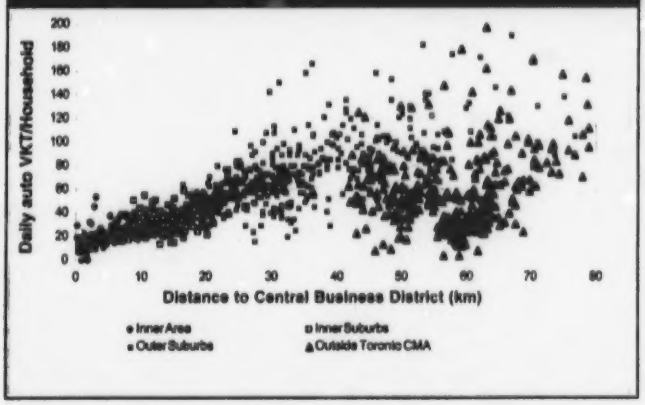
The following sections provide a preliminary examination of the possible relationships between locational characteristics and auto VKT.

Distance to the Central Business District

Exhibit 4 shows the relationship between auto VKT per household and the distance from the central business district (CBD). For zones within the Toronto CMA, it indicates a clear, linear relationship with auto VKT/household increasing as distance from the CBD increases. Exhibit 4 includes data for traffic zones outside the Toronto CMA. As expected, for these zones, the relationship becomes less distinct, perhaps due to the fact that many of these zones have a higher degree of self-containment and are not as reliant on the Toronto CBD as a work trip destination (especially Hamilton, Burlington, etc.). In part, this led to the decision that the analysis for this study be limited to the Toronto CMA. However, it also suggests that it is worthwhile to explore a locational variable based on the distance to the nearest urban centre or node (e.g., North York Centre, Scarborough Centre, etc.), in addition to a variable based on the distance to the CBD alone, as discussed in the next section.

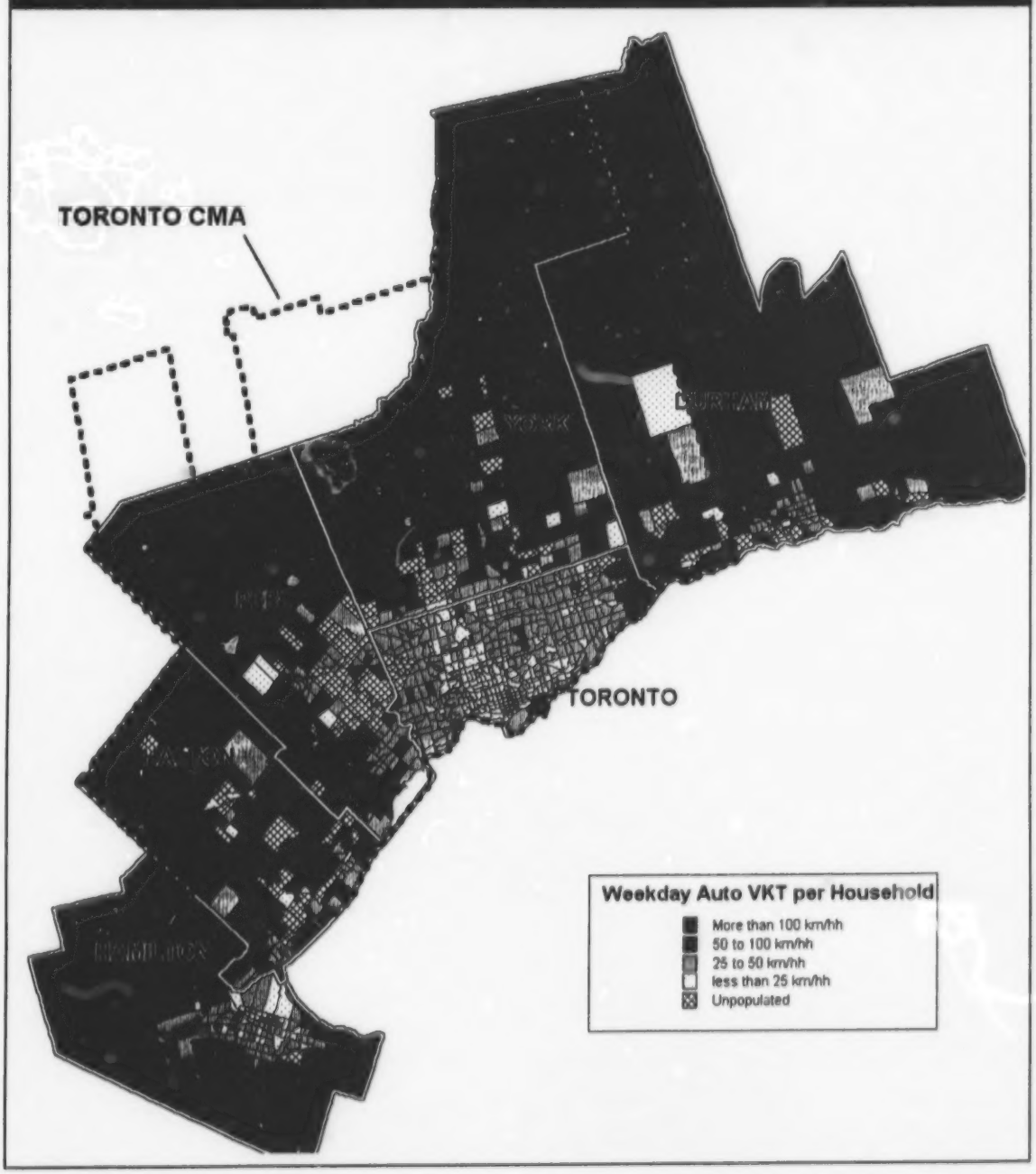
Exhibit 5 further emphasizes the relationship between location and average VKT/household. Very generally, those zones closer to the CBDs and closer to rapid transit and GO Transit stations have a lower intensity of auto travel.

Exhibit 4
Auto VKT vs. Distance to CBD



Approximately one out of every 13 jobs in the Toronto CMA is located within the CBD as it is typically defined.[4] Therefore, one could expect that the farther a zone is from the CBD, the greater the probability that people are travelling farther (on average) to work. This hypothesis is further strengthened by the fact that average employment density declines with distance from the CBD. Hence, workers living in the outer suburbs will have to travel further, on average, than workers living closer to the metropolitan centre, excepting those living close to sub-regional employment centres such as Oshawa.

Exhibit 5
Spatial Distribution of Daily Auto VKT/Household



While there is a high probability that a worker's job is located close to or in the CBD, other characteristics of the CBD are also important, such as the fact that it is the major hub for transit services in the GTA. Partially due to historical developments, and in combination with the fact that many people work in the CBD, most transit services in the GTA are oriented around the CBD. This tends to increase transit modal shares for CBD-bound trips with a corresponding reduction in auto VKT.

Distance to Nearest Employment Node

It is reasonable to expect that proximity to nodes of concentrated activities could reduce auto VKT/ household. A recent study by IBI Group (1997) defined 29 nodes of key significance in the GTA. Using these node definitions, there is a general trend of increasing VKT with increasing distance from the nearest employment node, but most of the data lie between one and seven kilometres to the nearest node, and no clear trend can be seen in this range.

A shortcoming of this variable is that it does not take into account the attractiveness of the employment node in terms of the number of jobs. That is, equal proximities to employment nodes of differing attractiveness are given the same value. A variable quantifying proximity to employment (see below) addresses this shortcoming.

Proximity to Employment

In this analysis, proximity to employment for a traffic zone was measured as the number of jobs within a certain radius of the traffic zone's population centroid.

The first measure used a one-kilometre radius, which represents a reasonable walking distance to work or services. The circle defined by this radius often captures only a few traffic zones or portions thereof. Therefore, employment was calculated based on the areas and employment densities of the portions of the traffic zones that fall inside the circle for an equivalent value of jobs within one kilometre. Exhibit 6 shows that, for each geographic area, the average auto VKT per household decreased with increased number of jobs within one kilometre in almost every case. The R^2 for a log-linear regression is a relatively strong 0.61.

A second measure of proximity to employment used a larger radius—five kilometres. The results are similar to those using a one-kilometre radius. Exhibit 7 shows that, for each geographic area, the average auto VKT per household decreased with increased number of jobs within a five-kilometre radius of the traffic zone centroid as well. However, the second employment proximity measure is more highly correlated with distance to the CBD than the first measure. The R^2 for the log-linear best fit curve for this measure is 0.694, stronger than the previous measure. In fact, the number of jobs within a five-kilometre radius of the neighbourhood centroid might be a good proxy for, and improvement over, the distance to the nearest employment node, as the attractiveness of the employment node in terms of job opportunities and available services is now taken into account.

Exhibit 6
Number of Jobs Within a 1-km Radius and Average Auto VKT/Household

	0-500 jobs	500 to 2,000 jobs	2,000 to 5,000 jobs	Over 5,000 jobs
Geographic Area	**VKT/household**	**VKT/household**	**VKT/household**	**VKT/household**
Inner area	*	21	26	18
Inner suburbs	66	38	30	28
Outer suburbs	87	62	49	33
TOTAL	**87**	**54**	**38**	**23**

Note:
* Data are insufficient for comparison

Exhibit 7
Number of Jobs Within a 5-kilometre Radius and Average Auto VKT/Household

	0-20,000 jobs	20,000 to 50,000 jobs	50,000 to 100,000 jobs	Over 100,000 jobs
Geographic Area	**VKT/household**	**VKT/household**	**VKT/household**	**VKT/household**
Inner core	*	I	29	19
Inner suburbs	65	43	32	30
Outer suburbs	85	60	43	44
TOTAL	**85**	**59**	**37**	**26**

Proximity to Transit Nodes

In the case of Toronto, zones within walking distance to rapid transit stations achieve transit modal shares several times higher than zones not within walking distance of a rapid transit station. The same holds true for zones close to commuter rail stations (GO Transit stations). Generally, there is a fairly strong linear correlation between the distance from either a rapid transit station or a GO Transit station, and auto VKT per household.

There are several options for incorporating a measure of the distance to transit stations into the model. One approach would be to take the lesser of the distance to a rapid transit station or a GO station. A second approach is to create two separate binary variables (whose values are zero if false or one if true) to reflect whether the zone lies within one kilometre of a rapid transit station as well as whether the zone lies within one kilometre of a GO station. Both approaches were tested in the model.

Local Transit Accessibility and Service

Residents are more likely to choose to use local transit services when an attractive transit alternative to the automobile serves the neighbourhood.

Transit information was available from the Toronto Transit Commission (TTC) which provides transit services to the City of Toronto. Measuring transit service was not a trivial task.

To ensure the size and shape of the traffic zone did not bias the measure of proximity to local transit service, the measure of a traffic zone's local transit proximity used in this study incorporated those segments of bus routes that pass through a circle defined by a one-kilometre radius from the population centroid of the traffic zone. One kilometre is somewhat further than most people would walk to catch a bus. This radius was used because a smaller one would not have captured routes on the boundaries of the more peripheral and larger traffic zones and, thus, would have understated the availability of transit service in these areas. Service hours for these segments are calculated as follows.

Weekday bus vehicle service hours = $d/v*t*f$

where

d = the total length of transit route segments passing through a circle of one-kilometre radius, centred on the neighbourhood centroid;

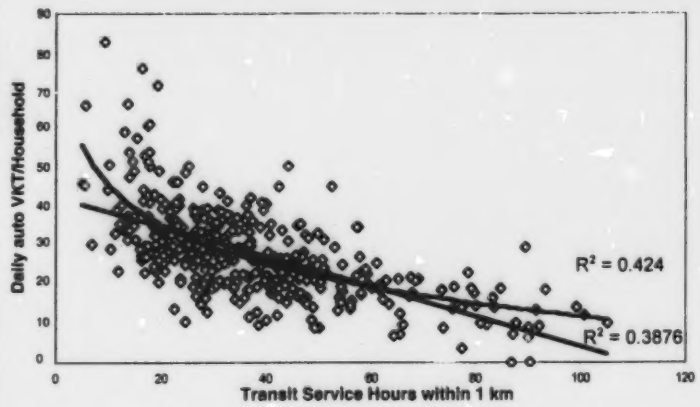
v = average bus speed (taken to be 25 km/h for our data set);

t = total weekday service hours; and

f = average bus frequency (number of buses on the route per hour).

Exhibit 8 shows the relationship between local transit service, as defined above, and auto

Exhibit 8
Auto VKT vs. Transit Service



VKT/household for Toronto only. As expected, there is a general trend toward decreasing VKT with increased transit service. The log-linear regression line plotted has a higher R^2 than the linear regression line, indicating "diminishing returns," in terms of reducing VKT, of increasing transit service indefinitely.

Determining transit service levels to the same level of detail for the entire GTA as for Toronto (TTC) was not feasible as data at the detailed route level were not available for the local transit services. A reasonable solution was to compare the overall transit service hours per unit area for various local municipalities on an overall basis with those of the City of Toronto.

Neighbourhood characteristics

Employment, Population and Household Density

While many studies indicate that density is a major influence on VKT, others maintain that because density is highly correlated to other variables, univariate regression analyses overestimate its explanatory power. For example, in Hunt Analytics Inc. (1999), population and employment density show little influence when they are included in multivariate regression runs as explanatory variables along with other correlated variables such as household income and mode-specific accessibilities. In the analysis of Toronto data, employment density is highly correlated with distance to the CBD, although there are also pockets of higher employment densities in communities in the outer areas of the GTA.

For the preliminary investigation, a plot of auto VKT vs. employment density (not shown) was generated. It showed a general trend toward decreasing VKT with increasing employment density. Because of the different impacts the traffic zone's size would have on employment density, a more standardized measure was preferred. An employment accessibility measure discussed previously—the number of jobs within a one-kilometre radius of the zone centroid—added better predictive strength to the model than did employment density by traffic zone.

In keeping with the methodology of this study, which focusses on *housing* development and household travel behaviour, household density, rather than population density, is tested as an independent variable influencing auto VKT. This measure also varies with distance from the CBD. There is a general trend toward decreasing VKT with increasing household density. The R^2 of the best fit log-linear regression line in this case is 0.56. But as discussed in Chapter 4, the effect of density decreases dramatically in the multivariate regression analysis.

In the same manner as employment density, it was found that choosing a more standardized area than the traffic zone within which to measure housing density resulted in a better model fit. The measure preferred in this study considered the amount of housing within a one-kilometre radius of the traffic zone centroid. The R^2 of the best fit log-linear regression line in this case is 0.61.

Land Use Mix

Hunt Analytics Inc. (1999) indicates that a mix of land uses in close proximity to housing increases walk, transit and cycle accessibility that, in turn, reduces auto use. Mixed land use in the vicinity of a household means the household has nearby options for activity locations, and is not as dependent on motorized transport. The scope of the current study includes only the land use mix of the household's home neighbourhood and does not include land use mix in the vicinity of a household member's work place or other activities.

A measure of the mix of land uses is difficult to quantify. A simplistic measure that was tested was the ratio of jobs to population within the neighbourhood, or within a one-kilometre radius of the centroid of the neighbourhood. However, this measure takes into account neither the density of jobs nor population. This variable was surprisingly weak in the univariate analysis of auto VKT/household. The R^2 for the best fit log-linear regression line was less than 0.01. This indicator had virtually no predictive power in the initial multivariate models tested.

Another measure of land use mix is one inspired by an indicator used in chemistry describing how well gases are mixed, and can be called an "entropy" measure. To use a measure that compares apples to apples in the model, it was decided to compare the number of jobs with the number of workers in a one-kilometre radius of the centroid of the neighbourhood.

In the entropy expression, the numerator is normalized to a value between 0 and 1, because there are two variables in the mix: workers and jobs. A value of zero indicates no mixing whatsoever, whereas a value of 1 indicates the land uses are evenly mixed.

Admittedly, this is still a simplistic measure of land use mixing. The true degree of mixing would be affected by the kinds of jobs and services available, within walking distance, to those in the neighbourhood. The spatial distribution of this measure also appeared quite random, and no clear relationship can be seen in a plot of land use mix and auto VKT. However, when combined with other variables in the multivariate regression model, this indicator proved to be quite robust, which highlights the value of multivariate analyses to separate the cumulative effects of the individual variables used.

Shopping Opportunities

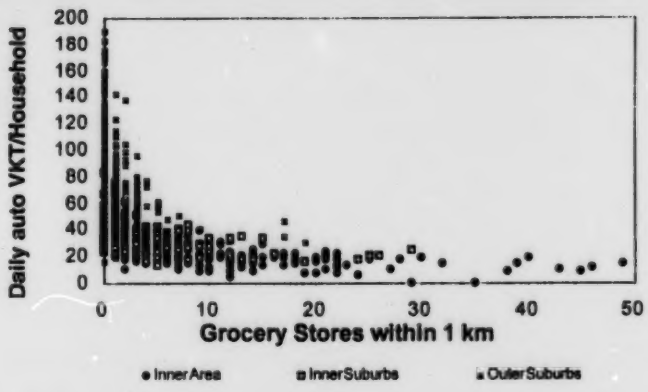
A household with shopping opportunities within walking distance of the household is expected to generate fewer VKT than those with no choice but to drive to procure goods.

No data summarizing locations of shopping opportunities in the GTA were found. Thus, it was necessary to generate an original indicator of neighbourhood shopping accessibility. Trying to note the locations of all stores would be very time consuming. Instead, the addresses of only grocery stores as found in the yellow pages[5] were noted, totalling 1,142 stores, and the locations of these stores were geo-coded (i.e., assigned map coordinates). A neighbourhood's measure of accessibility to shopping was the number of grocery stores within a one-kilometre radius of the neighbourhood centroid. Other measures related to this one were tried, such as a binary measure indicating whether there were any stores within a one-kilometre radius, or the natural log of the number of stores, but were not as strong in predicting VKT. In order for the measure as described above to be a true indicator of total shopping accessibility, various types of retail would need to be distributed in the same way as grocery stores. This, of course, is not quite the case in reality, but the measure seems to be a reasonable one. There is a trend of decreasing auto VKT with increasing shopping opportunities within one kilometre, as seen in Exhibit 9.

Structural Housing Types

It is expected that the relationship between housing type and auto VKT is largely attributable

Exhibit 9
Auto VKT vs. Shopping Opportunities within 1 kilometre



to the demographics of the people residing in the different housing types. That is, younger households are more likely to live in rental units, which are often in highrise buildings, than older households, who may be more settled and living in single-family homes.

Census data provide descriptions of housing types. Five structural housing types are considered in this analysis: fully detached houses, semi-detached houses, low-rise apartments and duplexes, highrise apartments and town/row houses.

At either end of a spectrum of housing types are single-detached houses and highrise apartment buildings. The R^2 for a linear regression line for a variable denoting single-detached housing was a moderate 0.44, but it was much lower for highrise apartments, at 0.051. The prevalence of different structural housing types, especially single-detached dwellings, is moderately correlated with locational variables such as distance to CBD and housing density. Therefore, multivariate regression is necessary to isolate the effects of housing types.

Housing mix may best be modelled in the same way as land use mix, that is, using an entropy-inspired measure. When auto VKT vs. housing mix is plotted, a trend of decreasing auto VKT with increasing housing mix is evident. The best fit regression line through these points had a minor R^2 of 0.23.

A final variable relating to the housing structures in a neighbourhood deals with the size of the units. This is measured in terms of the number of rooms, not including bathrooms, hallways or vestibules. Housing size is clearly correlated with the mix of housing types and housing density: a large average housing unit size is incompatible with high housing densities, and large units are often single fully detached houses. Moreover, a large average unit size also usually precludes smaller or younger households from living in the neighbourhood. When auto VKT vs. housing size is plotted, a definite trend toward increasing auto VKT with increasing average housing size is evident. A log-linear best fit line through these points has a moderate R^2 of 0.43.

Road Layout/Configuration

There are many hypotheses about how road configuration and road extent impact vehicle usage. In particular, curvilinear road patterns tend to make walking distances between activities longer, and reduce the efficiency of transit service. This is illustrated by the contrasting examples of neighbourhood design shown in Exhibit 10, in which an auto-dependent layout is illustrated in the upper half and a transit-oriented layout in the lower part.

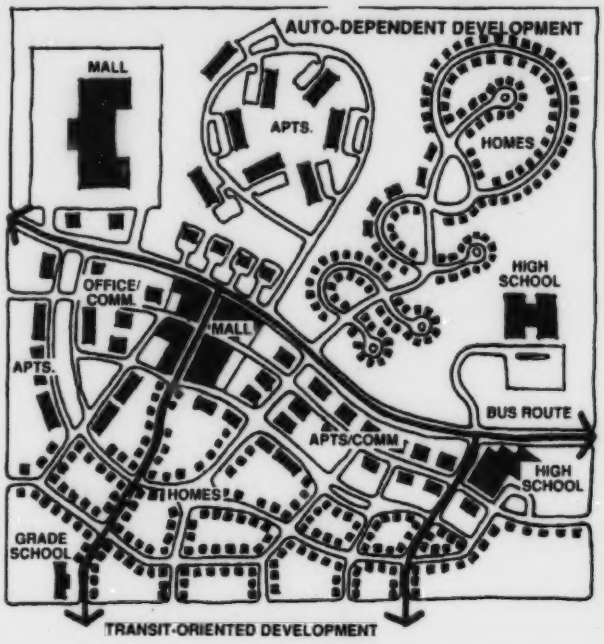
Hunt Analytics Inc. (1999) found that regular, rectangular street patterns tend to be associated with slightly less auto use than curvilinear street patterns. It is also believed that traffic generally expands to fill the space available to it. For example, a study by Hansen (1995) found that a one per cent increase in lane miles

induces a 0.9 per cent increase in VKT within five years.

The first type of road variable explored was road layout pattern. For each traffic zone within the GTA, road patterns were manually classified according to the following general types (adapted from Hunt Analytics Inc. 1999).

- *Strict rectangular grid* used to describe zones that contain exclusively urban grid networks, typical of pre-1950s development.
- *Industrial grid* added to describe areas with fairly widely spaced roads passing through primarily industrial areas. It was hypothesized that these types of zones may generate different travel patterns than the above category.
- *Primarily rectangular grid* consists of grid networks with some diagonal breaks.
- *Mix of rectangular and curvilinear* is used to describe zones where there is a predominance of curvilinear streets intermixed with a grid network.
- *Regular curvilinear* is used to describe zones consisting primarily of curved streets with at least some continuity between the streets.
- *Random curvilinear* is used to describe zones with road layout patterns typical of post 1970s development consisting of a high proportion of streets ending with cul-de-sacs and butting onto large arterial roadways (e.g., upper portion of Exhibit 10).
- *Rural grid* describes zones in the outer areas of the GTA that are largely undeveloped and consist of widely spread regional arterials, township roads and rural highways.

Exhibit 10
Auto-Oriented Development vs. Transit Oriented Development

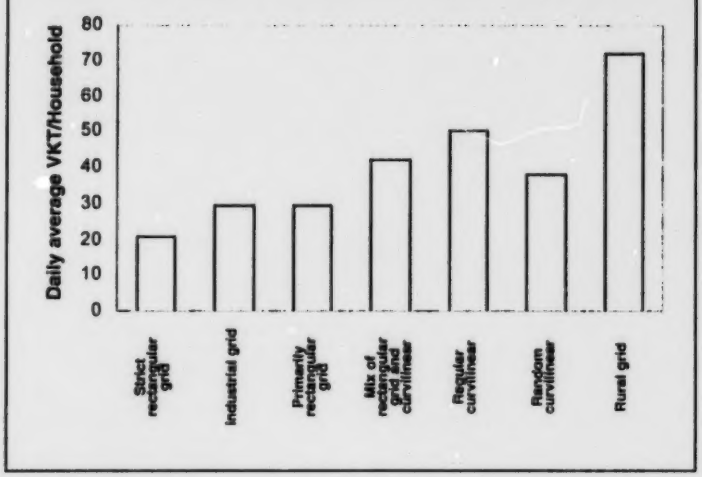


Source: Ministry of Transportation, Ministry of Municipal Affairs of Ontario. (1992).

As shown on Exhibit 11, there is a very high degree of correlation between road patterns and VKT among travel zones in the study area, with grid networks corresponding to the lowest VKT/household and rural grids and curvilinear road layouts corresponding to a higher average VKT per household. As with most other variables, the type of road layout is correlated to other variables such as urban context and population density. Despite this, it would seem that road layout has some potential to explain VKT patterns.

Another possible indicator of road layout is the number of intersections per road-kilometre. This is a numerical measure of the connectivity of the roads in a neighbourhood and of the number of alternative routes available for trips. Many auto-oriented developments minimize the number of

Exhibit 11
Road Layout Patterns vs. VKT/Household



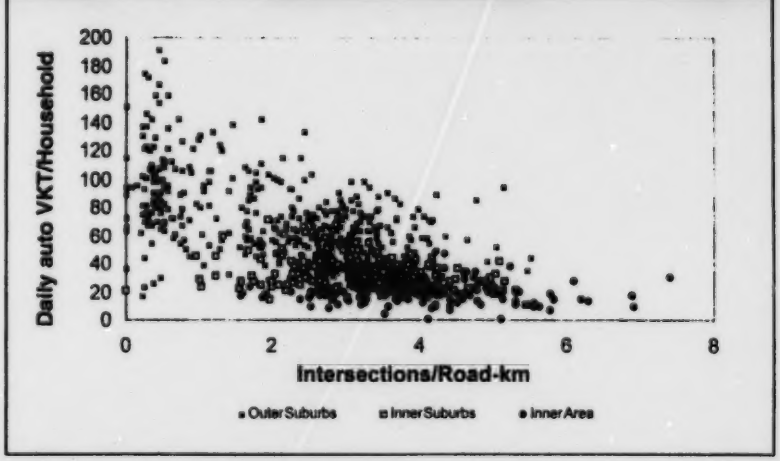
intersections along a roadway, as vehicular movement is impeded at intersections. However, what aids automobiles is a hindrance to pedestrians and cyclists, as unreasonably long walking distances to activities often result. Having a denser network of roadways, accompanied by more intersections per road-kilometre, increases the number of route choices and increases the probability of finding a shorter route to one's destination. It was decided to use the number of intersections per road-kilometre rather than the number of intersections per unit area, as the latter would discriminate against zones with larger parks or undeveloped areas, which would have neither roads nor intersections. A plot shows that the number of intersections per road-kilometre is indeed inversely correlated with auto VKT (Exhibit 12). The linear best fit line has an R^2 of 0.41.

Road Extent

It is expected that an increase in the supply of roads would encourage greater vehicle use and VKT. When plotting auto VKT/household vs. road-kilometres/household, there is a fairly distinct positive trend. The best fit log-linear curve has an R^2 of 0.42. However, with the apparent undesirable relationship between road provision and VKT, there is a risk that urban planners may not provide enough streets to ensure that walking distances are minimized and connectivity is maintained. Therefore, we have not incorporated this variable into the preferred model definition.

As a measure of the "pedestrian friendliness" of the streets, variables indicating the presence of wide arterial roads (3 or more lanes per direction) were examined. Pedestrians and cyclists are far more likely to use a narrower, slower-speed street than a wide, fast-moving arterial. Various forms of this variable were tested, including a binary variable denoting the presence of wide arterial roads in the traffic zone. Another was the ratio of the total length of wide arterial roads to the total length of roads, excluding expressways and ramps in the traffic zone. The latter was found to be a statistically significant predictor of auto VKT in the

Exhibit 12
Auto VKT vs. Intersections/Road-Kilometre



multivariate analysis. As a result it was retained for the final model.

Lane-km per household is another potentially suitable measure; however, information on lane-km was only available at the aggregate level of GTA local municipalities, wherein there can be much variation in lane-km between neighbourhoods within the same local municipality. Due to this lack of data at the neighbourhood zone level, the lane-km variable was not included in the model.

Bike Routes

The degree to which bicycling is encouraged through the provision of bike routes in the neighbourhood is also expected to decrease automobile use. The total length of roadways with bike lanes or designated shared lanes ("on-street bike routes") were determined for each traffic zone in the City of Toronto. Very limited information was available for outer areas, mainly due to the lack of bike routes. For the purpose of this study, all areas outside of Toronto were assumed to have minimal bike routes suitable for non-recreational travel.

Bike route variables tested included binary variables indicating whether any bike routes or on-street bike lanes existed in the traffic zone, and the ratio of on-street or total bike routes to total roadway lengths within that traffic zone. It is recognized that these are somewhat simplistic variables; a more comprehensive measure of the extent to which biking is encouraged would also take into account the connectivity of the bike routes in the traffic zone with other bike routes, and the safety and quality of the bike routes. Nevertheless, these bike route variables were found to be statistically significant predictors of vehicle ownership and transit use in the multivariate analysis.

Parking Characteristics

Hunt Analytics Inc. (1999) found that a $0.50 increase in parking costs at work destinations in Edmonton decreased auto VKT by 3.4 per cent. However, the current study did not explicitly incorporate a measure of parking availability or cost. It is beyond the scope of the current study to predict the locations and neighbourhood design characteristics (e.g., parking availability) of household members' work and other activity places. This study focusses on the explanatory variables at households' home neighbourhoods only and, as such, the effect of parking availability for housing is the prime interest. However, municipalities generally do not keep track of residential parking availability, and assembling the data would prove to be very time consuming due to the variety of parking types available.

Other Neighbourhood Characteristics

Numerous other neighbourhood attributes were considered for inclusion in the regression model, including streetscaping, traffic calming and pedestrian facilities. For some of these, efforts to procure appropriate data were unsuccessful, or preliminary research suggested these variables are generally not significant in regressions of auto use as they are greatly outweighed by factors such as location.

It was found that assembled information on traffic calming initiatives for the GTA is not extensive. Furthermore, most of the traffic-calming initiatives reported for downtown Toronto were implemented after 1996, so the 1996 TTS data would not reflect the impacts of these changes.

Including a variable denoting the effect of streetscape quality on auto or transit use is highly desirable. One approach tested for this study was to inspect the values of auto VKT that were predicted using the final model for a number of traffic zones where differences in streetscape were quite obvious. The result of this approach was that no systematic bias in the model results that could be corrected by a streetscaping variable was detected. In fact, for a number of these zones, trying to correct the predicted values by introducing this variable would result in an unexpected (counter-intuitive) sign for

its coefficient. Hence, no variable denoting streetscape quality was applied in the model. This does not imply that streetscaping has no effect on household travel behaviour, but only that the data set does not seem to be sensitive enough to changes in this variable for it to be statistically significant in the final model specifications.

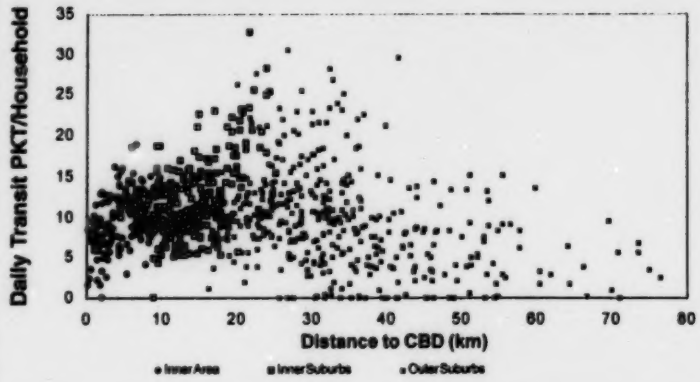
Variables impacting transit usage

Analysis of individual variables impacting transit PKT was also carried out. Univariate regression analyses where transit PKT per household is the dependent variable showed that none of the variables approach the strength of the key variables in the auto ownership or auto VKT univariate analyses, where R^2 values could be as high as 0.70. For transit PKT, the univariate analysis suggests that the strongest explanatory variables are those related to the size of the household (e.g., number of persons per household or its natural logarithm, with R^2 values of 0.11). Proximities to rapid transit stations or GO stations also seem to be among the more promising variables.

The square of the distance to the CBD was also tested. The reason for doing so may best be explained with the help of Exhibit 13, which shows a plot of transit PKT vs. distance to the CBD. It can be seen that within roughly a 25-kilometre distance to the CBD, there is a trend of increasing transit PKT with increasing distance to the CBD. This can be explained by the fact that transit passengers need to travel longer distances on average. However, further from the CBD, transit PKT decreases with increasing distance to the CBD. This is due to the lower proportion of trips made by transit overall. Although transit trips may become longer still, there are fewer of them, so total PKT decreases. A linear best fit line shows a slight decrease of transit PKT with increasing distance from the CBD, but has an R^2 of only 0.034; a quadratic line (with both a linear and a quadratic term) fits much better, with an R^2 of 0.107. A quadratic line could be "linearized" for use in the multivariate regression equation by including two terms, one for distance to the CBD, the coefficient of which is expected to be positive, and one for the square of this distance, the coefficient of which is expected to be negative.

Another term that was examined was the distance to the CBD when a rapid transit station was within one kilometre of the node centroid. When a rapid transit station is not within one kilometre, the value of this variable was set at zero. This combined variable reflects both the increased propensity of a household to use transit because rapid transit is very accessible, and also the distance the household members would travel. In the same way, a third additional variable tested was the distance to the CBD when a rapid transit station was within two kilometres of the node centroid. Using a two-kilometre threshold value for the commuter rail variable resulted in a stronger variable than using a one-kilometre distance; it also seems reasonable that people might travel a little farther to reach a GO station than they would to a rapid transit station because of the increased time savings for their overall trip.

Exhibit 13
Daily Transit PKT vs. Distance to CBD



4. MODEL DEVELOPMENT

Methodology

The approach adopted for this study is based on multivariate regression that, essentially, makes it possible to examine how a single dependent variable (e.g., VKT/household) is affected by the values of one or more independent variables. The basic form of the model is:

$$Y = a + b1X1 + b2X2 + \ldots + bnXn$$

where Y = dependent variable

X = independent variable

a = constant term

b = coefficient term

In effect, the contributions of the different explanatory variables to the dependent variable become cumulative. The coefficients assigned to the individual variables in the best fit model indicate the degree to which the variables would affect the dependent variable if they could be isolated, that is, if the other independent variables were held constant.

The model is estimated using a least squares method, which can be thought of as fitting a straight line through a set of observations. This implies that the independent variables are "linear-in-the-parameters." The explanatory variables can be "linearized" using various transformations such as logarithmic forms, as identified in the model equations. Some of the explanatory variables have been included as a form described as "binary variables." Such variables have only two possible values: 0 if the stated condition (e.g., whether there is a rapid transit station within one kilometre) is false, or 1 if the condition is true. The univariate analyses of Chapter 3 provide an indication of appropriate functional forms for many of the variables (eg. binary, logorithmic etc.).

Simultaneous regression analysis was used to develop the final specifications of the auto ownership and auto VKT models. The auto VKT model therefore uses predicted values of auto ownership. The simultaneous regression approach optimizes the model fit for both dependent variables, auto ownership and auto VKT, at the same time.

The final specifications of the transit PKT model also use predicted values of auto ownership, but this model was calibrated separately from the first two models. This is because the R^2 values for the auto VKT and auto ownership models are quite good at 0.84 and 0.88, respectively, whereas the R^2 for the transit model is only a moderate 0.33.

In general, the following criteria or considerations were used in evaluating the test models and the appropriateness of including various explanatory variables.

- The R^2 values are a statistical measure of the overall goodness of fit of a model, and as such, the best model would have R^2 value close to 1 or -1.

- The sign of the coefficient of the explanatory variable should not be counter-intuitive.

- The t-statistic is a measure of the significance of the parameter estimates. The t-test, as it is called, measures the level of confidence that the true value of the coefficient of the variable is non-zero, and so the assumption that the associated independent variable has a statistical relationship with that dependent variable is valid. Absolute values greater than 1.65 indicate that the coefficient is *statistically significant* at the 95 per cent confidence level for this data set.

- One piece of evidence of a *robust* explanatory variable is that the magnitude of its coefficient remains roughly constant

as the model specification is altered. If the coefficient value varies greatly, this may be an indication that there is a high correlation between it and another variable in the model.

- One sign of a good model based on a simultaneous regression approach is that the specifications for the component sub-models should not be greatly different from the same models using simple multivariate regression analyses. A large change in the model parameters when simultaneous regression is performed may suggest that a variable in one sub-model may be compensating for a missing variable in another sub-model.

Results of Multivariate Regression Analyses

Auto ownership sub-model

Exhibit 14 shows the results of several simple multivariate regression analysis test runs. This is only a sample of the numerous potential model formulations that were tested, both individually and simultaneously with the auto VKT model. In general, here and for the other sub-models, simpler models were tested first, then the models were made more complex by adding more variables.

Several variables that are significant in the model of vehicles per household are not significant in the auto VKT model, as discussed below. Although variables in the auto ownership model indirectly affect auto VKT, the impacts of these variables are "watered down," and their effect is not as strong as if they were incorporated into the auto VKT model directly.

The following discussion describes some results of the multivariate regression analysis, including whether or not each explanatory variable was included in the final model and the rationale behind that decision.

- The average **number of adults per household** variable was selected for the final model. It is robust, statistically significant and the sign makes sense (+). Using this variable rather than the number of persons per household tended to result in a slightly better overall model fit.

- Because the **household employment income** variable (the natural logarithm form rather than the linear form) was statistically significant and satisfied the other criteria, it was selected for the final model specification.

- Two variables describing **housing density** were tested, the first taking into account the natural logarithm of the housing density within the neighbourhood only, the second being the natural logarithm of the number of housing units within a one-kilometre radius of the node centroid. The latter provides a more standardized measure that conceptually has the same impact regardless of the size of the neighbourhood being evaluated, and also resulted in a better fit in the model runs. It was robust, statistically significant and the sign was as expected. Therefore it was selected for the final model.

- **Distance to the CBD** was statistically significant and was selected for the final model. When this variable was not included, variables denoting neighbourhood housing density and bus vehicle service hours picked up most of the slack, as these variables are correlated with distance to the CBD.

- **Bus vehicle service hours** are intuitively an important factor in household vehicle ownership decisions, since an attractive alternative to automobile ownership and usage gives a household real travel options. The variable was robust, statistically significant and the sign was as expected. Therefore, it was selected for the final model. The coefficient of the distance to the CBD variable is reduced by half when the variable denoting bus vehicle service hours is introduced to the mode. The strong interrelationship of these two variables is very noteworthy.

Exhibit 14
Vehicle Ownership/Household: Simple Multi-Variate Regression Test Model Runs

Variable	Expected Sign	Model Run																			
		All Vars.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20*
Constant		-2.03 (-6.99)	0.939 (10.2)	0.375 (3.70)	0.433 (5.19)	0.478 (5.58)	0.313 (3.39)	0.325 (3.41)	0.447 (3.44)	0.341 (3.40)	0.289 (3.12)	0.384 (4.02)	0.371 (3.78)	0.374 (3.58)	0.772 (9.73)	0.597 (5.58)	0.384 (3.68)	-2.53 (-9.96)	-2.52 (-9.94)	-2.53 (-9.96)	-2.54 (-9.97)	-2.46 (-9.79)
Distance to CBD (km)	+	0.00369 (2.95)	0.0087 (6.67)	0.0122 (12.84)	0.0116 (15.2)	0.00905 (7.08)	0.00574 (6.86)	0.00564 (6.58)	0.00468 (4.23)	0.00568 (6.74)	0.00604 (7.19)	0.00748 (8.02)	0.00568 (6.62)	0.00568 (6.59)		0.00542 (6.3)	0.00589 (6.66)	0.00521 (6.25)	0.00519 (6.21)	0.00528 (6.31)	0.00529 (6.22)	0.00466 (5.43)
ln (housing within 1 km)	-	-0.0568 (-4.96)	-0.107 (-12.9)	-0.0837 (-10.3)	-0.0628 (-9.45)	-0.095 (-10.6)	-0.0515 (-8.05)	-0.0483 (-5.51)	-0.0442 (-5.47)	-0.0513 (-8.02)	-0.0501 (-7.85)	-0.581 (-8.80)	-0.0544 (-8.08)	-0.0546 (-7.14)	-0.0799 (-14.1)	-0.0568 (-8.44)	-0.0588 (-7.76)	-0.0589 (-8.59)	-0.0570 (-8.59)	-0.0568 (-8.53)	-0.0570 (-8.59)	-0.0590 (-8.66)
Adults/household	+	0.4466 (18.9)		0.661 (24.0)	0.562 (24.7)	0.513 (23.9)	0.473 (20.6)	0.473 (20.6)	0.478 (20.7)	0.473 (20.6)	0.472 (20.7)	0.463 (19.9)	0.455 (19.0)	0.455 (19.0)	0.443 (18.1)	0.472 (20.2)	0.458 (19.1)	0.447 (19.1)	0.446 (19.0)	0.448 (19.1)	0.445 (18.9)	0.44 (18.7)
Household emp. income ($1,000)	+				0.00785 (20.8)	0.00648 (17.4)	0.0048 (10.8)	0.00485 (10.7)	0.00486 (10.7)	0.00481 (10.6)	0.00472 (10.5)	0.0048 (10.4)	0.00491 (10.5)	0.00491 (10.5)	0.00482 (9.7)	0.00574 (14.3)	0.00486 (10.3)					
ln (household emp. income)	+	(.28) (11.2)																0.3019 (12.1)	0.302 (12.1)	0.300 (12.0)	0.303 (12.1)	0.301 (12.1)
Weekday transit vehicle service hours (1-km radius)	-	-0.00263 (-3.69)				-0.00581 (-11.6)	-0.00511 (-9.87)	-0.00508 (-9.75)	-0.00511 (-9.89)	-0.00517 (-9.87)	-0.00405 (-8.36)	-0.00354 (-5.5)	-0.00409 (-8.42)	-0.00408 (-8.41)	-0.00613 (-10.7)	-0.00446 (-7.1)	-0.00412 (-8.47)	-0.00389 (-8.22)	-0.00388 (-8.22)	-0.00390 (-8.24)	-0.00390 (-8.23)	-0.00386 (-8.39)
Housing typologies mix	-	-0.116 (-3.91)					-0.11 (-3.65)	-0.111 (-3.7)	-0.107 (-3.52)	-0.108 (-3.55)	-0.106 (-3.54)	-0.118 (-3.94)	-0.109 (-3.62)	-0.109 (-3.62)	-0.121 (-3.94)	-0.0779 (-2.34)	-0.107 (-3.54)	-0.117 (-3.98)	-0.118 (-4.00)	-0.113 (-3.80)	-0.117 (-3.99)	-0.121 (-4.12)
Rooms/housing unit	+	0.0328 (3.52)					0.0442 (4.79)	0.0436 (4.68)	0.044 (4.78)	0.0443 (4.80)	0.0455 (4.94)	0.0425 (4.59)	0.0426 (4.57)	0.0426 (4.56)	0.0422 (4.40)		0.0437 (4.67)	0.0343 (3.72)	0.0338 (3.64)	0.0356 (3.82)	0.034 (3.68)	0.0339 (3.66)
Number of stores within 1 km	-	(-) (-2.13)									-0.00422 (-2.81)	-0.00399 (-2.58)	-0.0033 (-2.14)	-0.0033 (-2.13)	-0.0016 (-1.02)	-0.00264 (-1.71)	-0.00359 (-2.3)	-0.00231 (-1.51)	-0.00233 (-1.53)	-0.00230 (-1.51)	-0.00213 (-1.36)	-0.00232 (-1.53)
Rapid transit station within 1 km (binary)	-	-0.0307 (-1.34)										-0.0368 (-1.64)	-0.0312 (-1.38)	-0.0312 (-1.37)	-0.0494 (-2.12)	-0.0397 (-1.74)	-0.0299 (-1.31)	-0.0512 (-2.26)	-0.0510 (-2.25)	-0.0506 (-2.23)	-0.0494 (-2.14)	-0.0534 (-2.32)
Distance to transit (RT or GO) (km)	+	-0.00874 (-4.03)										-0.00851 (-4.08)										
Curvilinear road layout	+	0.0335 (1.99)											0.0291 (1.80)	0.0287 (1.68)	0.0422 (2.57)	0.0352 (2.16)	0.0292 (1.81)	0.25 (1.58)	0.0256 (1.61)	0.0246 (1.56)	0.0251 (1.58)	0.0288 (1.64)
Rural road layout	+	0.0300 (1.15)												-0.00185 (-0.08)								
% Detached housing	+	0.00237 (2.59)														0.128 (3.42)						
Intersections/road-km	-	0.0163 (2.1)															0.01003 (1.41)					
road-km/household	+	-2.42E-04 (-1.46)															0.0000258 (0.52)					
Persons/household	+		0.408 (22.4)																			
ln (jobs within 1 km)	-	-0.0160 (-1.72)						-0.00405 (-0.52)														
ln (jobs within 5 km)	-	-0.0223 (-1.76)							-0.0164 (-1.47)													
Land-Use Mix	-	0.0317 (.69)								-0.0322 (-0.72)												
3-lane arterial roads - binary	+																		-0.00748 (-0.399)			
Ratio of 3-lane arterial road to other road lengths	+	0.185 (1.46)																		0.129 (1.033)		
Ratio of on-street bike routes to total road lengths	-																				-0.0983 (-0.49)	
Ratio of total bike routes to total road lengths	-	-0.140 (-1.54)																				-0.243 (-2.81)
R^2		0.884	0.748	0.754	0.849	0.863	0.878	0.878	0.871	0.878	0.871	0.875	0.872	0.872	0.865	0.871	0.873	0.877	0.877	0.877	0.877	0.878

Notes:

0.000 variable coefficient
(0.000) t- statistic

ln = natural logarithm of variable

* Variables shown in the shaded column represent those which were used in the final model.

- The **distance to either a rapid transit station or a GO station** was tested as an explanatory variable in several different forms. A variable representing the actual distance to transit had a reasonable t-statistics in some runs but did not hold a consistent sign when used in combination with some other key variables. A binary variable denoting whether there was a rapid transit station within one kilometre was the only variable that consistently retained the expected sign of the coefficient and it was, therefore, selected for the final model specification.

- Variables that describe housing typology tend to improve the model fit. The coefficient values indicate that a high degree of **housing types mix** can reduce auto ownership and, as a result, was specified in the model. The variable denoting the average size of a neighbourhood's housing units, in rooms per unit, was also robust and statistically significant. The percentage of detached housing in an area was also robust for a number of model runs, but tended to reduce the statistical significance of other variables when it was included, perhaps because of a higher degree of correlation with these other variables. Rooms per household was favoured over this variable in the final model, as it resulted in a slightly stronger overall model fit, and also because the policy implications of the model results seem clearer.

- Variables denoting **proximity to work** and services—jobs within a one- or five-kilometre radius—were tested in several runs but tended not to be statistically significant in the auto ownership sub-model. However, the two variables were retained for the final model because of good results in the auto VKT and transit PKT sub-models.

- **Land-use mix** (balance between housing and jobs) was not statistically significant in this sub-model, although it was retained in the auto VKT model.

- **Proximity to shopping** was retained for the final model because it is statistically significant and meets the other criteria.

- The only binary variable to denote different **road layout types** that was statistically significant and gave the expected coefficient sign was a variable denoting a curvilinear road type, which includes both random and regular curvilinear streets. The final auto ownership model includes a binary variable denoting curvilinear road type with a positive coefficient sign.

- The variables **road-kilometres per household** and **intersections per road-kilometre**, were not statistically significant in the auto ownership runs tested, although intersections per road-kilometre was significant in the auto VKT sub-model. As a result, only intersections per road-kilometre was retained in the final model specification.

- Variables denoting the presence or extent of **arterial roads** were not statistically significant in the model runs and were therefore not included in the final auto ownership model, (but were included in the auto VKT model).

- The variable denoting the ratio of the length of **bike routes** to total roadway lengths in the traffic zone was statistically significant and was retained in the final model.

The highest R^2 values achieved for a rational auto ownership sub-model (i.e., a model in which the explanatory variables used were statistically significant and had the expected coefficient sign) using a simple multivariate regression approach was 0.88 in run 20. This is an excellent result considering the many factors that go into auto ownership decisions.

Auto VKT sub-model

Using a univariate regression analysis approach, many of the variables show excellent potential to

predict auto VKT per household. The strongest of these is distance to CBD, with an R^2 of 0.72, followed by the natural logarithm of the number of jobs within a five-kilometre radius (R^2 of 0.69), then auto ownership (R^2 of 0.67). It is extremely important to acknowledge that there is a high degree of covariance between some of these variables, which can lend high explanatory power from one variable to another that is correlated with it. The effects of the individual variables can be isolated using multivariate regression.

Exhibit 15 shows the results of some of the many simple multivariate regression analyses that were carried out using weekday auto VKT as the dependent variable. Listed are some of the observations made regarding the performance of these variables in the regression analysis.

- **Auto ownership** per household had coefficient values in the order of 20 to 25. The variable was statistically significant and the sign was as expected. Therefore, it was retained for the final model.

- Variables denoting **household size** were statistically significant and met the other criteria, so they were retained for the final model. There seemed to be no significant difference in the strength of linear expression of household size and its natural logarithm. In the end, the natural logarithm form of this variable was chosen because it had a slightly better fit in the univariate analysis, and it is also intuitive that there are some economies of scale for travel needs in larger households, as the natural logarithm implies.

- Individual **worker income** (expressed here in $000s) seemed to be a more robust and statistically significant variable than household income. It was retained in the final model.

- The variable, **distance to the CBD**, was statistically significant and was retained for the final model. When this variable was not included in the model tests, the coefficient of the variable denoting job accessibility within five kilometres increased in strength. The relationship between these two variables is discussed in the next point. The coefficient of the distance to rapid transit or GO Transit variable also increased in strength.

- The natural logarithm of the number of **jobs within a five-kilometre radius** of the node centroid was the only variable that caused a significant drop in the distance to CBD variable's coefficient, reducing its value by almost half.[6] The number of jobs within five kilometres variable tended to have a larger t-statistic and coefficient than a variable denoting the distance to the nearest employment node, and was also preferred for the reasons discussion in Chapter 3. It was retained for the final model.

- Including another measure of **proximity to employment**, the number of jobs within one kilometre, tended to result in an unexpected sign of the coefficient and was therefore not included in the auto VKT sub-model. It was significant in the transit PKT sub-model.

- **Land use mix** was statistically significant and robust, and the signs were as expected. Therefore, it was retained for the final model.

- The variable, **road-kilometres per household**, was statistically significant and had the expected coefficient sign, but because of adverse policy implications (i.e., compromising the connectivity of streets in reducing total roadway length), this variable was not included in the final model.

- The variable, **intersections per road-kilometre**, was statistically significant and gave the expected coefficient sign (negative). As a result, it was retained in the final model specification.

- The final auto VKT model includes a binary variable denoting a rural grid road type that is quite significant statistically and has a moderately high coefficient value. This was

Exhibit 15
Auto VKT/Household: Simple Multi-Variate Regression Test Model Runs

Variable	Expected Sign	Model Run																					
		All Vars.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22*
Constant		44.0	-13.8	26.5	60.6	58.7	58.7	45.2	40.7	26.5	29.6	29.7	29.6	20.12	32.1	32.42	29.3	34.2	77.5	77.0	33.0	32.7	32.0	32.24
		(3.78)	(-8.76)	(6.14)	(6.97)	(-6.75)	(6.77)	(4.82)	(4.31)	(2.71)	(3.07)	(3.11)	(3.08)	(2.01)	(3.35)	(3.33)	(2.97)	(3.56)	(9.55)	(9.18)	(3.40)	(3.34)	(3.26)	(3.31)
Distance to CBD (km)	+	0.0019	1.12	0.65	0.656	0.662	0.660	0.618	0.647	0.650	0.628	0.629	0.634	0.733	0.596	0.625	0.643	0.635			0.629	0.618	0.625	0.624
		(0.478)	(23.6)	(8.63)	(8.77)	(6.75)	(8.38)	(8.14)	(8.48)	(8.53)	(8.33)	(8.46)	(8.51)	(9.10)	(7.90)	(8.38)	(8.57)	(8.57)			(8.47)	(8.09)	(8.38)	(8.38)
Vehicles/household (observed)	+	25.8	27.2	25.5	25.7	24.6	21.8	23.4	20.5	22.1	21.5	21.4	21.9	24.0	22.9	21.4	21.3	24.7	26.2	26.5	21.6	21.4	21.4	21.2
		(11.3)	(19.21)	(16.5)	(16.8)	(9.06)	(12.0)	(12.6)	(9.75)	(10.5)	(10.3)	(10.5)	(11.1)	(11.6)	(11.5)	(10.6)	(10.7)	(11.6)	(13.2)	(12.7)	(10.9)	(10.7)	(10.7)	(10.65)
ln (jobs within 5 km)	-	-4.83		-4.94	-4.77	-3.49	-3.69	-2.90	-3.14	-3.20	-3.38	-3.33	-3.19	-3.22	-4.6	-3.13	-2.88	-3.84	-6.89	7.41	-3.33	-3.13	-3.18	-3.26
		(-5.52)		(-7.88)	(-7.67)	(4.37)	(-4.61)	(-3.66)	(-3.65)	(-3.94)	(-4.19)	(-4.78)	(-4.62)	(-4.66)	(-5.3)	(-4.52)	(-4.11)	(-5.15)	(-12.3)	(-11.2)	(-4.81)	(-4.52)	(-4.58)	(-4.67)
Land-use mix	-	-9.38			-12.5	-12.2	-12.1	-10.9	-10.8	-9.53	-9.41	-9.42	-9.61	-9.03	-10.7	-9.63	-10.2	-9.26	-8.87	-9.11	-10.06	-9.81	-9.51	-9.66
		(-2.84)			(-3.97)	(-3.87)	(-3.87)	(-3.47)	(-3.46)	(-3.08)	(-3.04)	(-3.08)	(-3.10)	(-2.88)	(-3.44)	(-3.18)	(-3.30)	(-3.01)	(-2.74)	(-2.83)	(-3.26)	(-3.16)	(-3.06)	(-3.07)
ln (housing within 1 km)	-	0.163				-1.47	-1.71	-1.36	-1.35	0.131	0.69604							1.28		1.4				
		(0.19)				(-2.53)	(-2.91)	(-2.29)	(-2.29)	(0.167)	(0.014)							(3.64)		(1.98)				
Persons/household	+						3.02	2.63	4.33	4.36	4.17	4.20												
							(2.53)	(2.21)	(3.29)	(3.35)	(3.21)	(3.27)												
ln (persons/household)	+	10.6											9.81	10.2	10.9	9.62	10.1	12.6	10.1	8.73	11.2	9.62	10.0	10.4
		(3.67)											(2.83)	(3.06)	(3.24)	(2.88)	(3.02)	(3.89)	(2.9)	(2.47)	(3.33)	(2.87)	(2.97)	(3.07)
Distance to transit (RT or GO) (km)	+	0.748						0.564	0.569	0.531	0.512	0.51	0.516	0.43	0.566	0.528	0.515	0.515	0.72	0.782	4.94	0.535	0.522	0.534
		(4.08)						(3.62)	(3.61)	(3.46)	(3.33)	(3.35)	(3.39)	(2.79)	(3.70)	(3.46)	(3.38)	(3.40)	(4.58)	(4.84)	(3.25)	(3.46)	(3.42)	(3.46)
Employment income ($1000)	+	0.171							0.146	0.136	0.132	0.133	0.128	0.15	0.127	0.136	0.142	0.204	0.0797	0.0857	0.128	0.134	0.138	0.139
		(2.92)							(2.96)	(2.67)	(2.72)	(2.72)	(2.6)	(3.06)	(2.56)	(2.76)	(2.88)	(3.88)	(1.39)	(1.68)	(2.56)	(2.78)	(2.78)	(2.81)
Rural road layout	+	3.51								6.08	7.18	7.08	7.22	6.95	8.25	5.97	6.07	7.10	6.97	6.44	5.71	6.01	6.12	5.91
		(1.88)								(3.60)	(4.54)	(5.10)	(5.19)	(4.62)	(5.74)	(3.73)	(3.79)	(5.12)	(4.79)	(3.63)	(3.58)	(3.75)	(3.80)	(3.89)
Curvilinear road layout	+	-1.62								-2.18														
		(-1.34)								(-1.84)														
Daily bus vehicle service hours, 1 km	-	0.056												0.12										
		(1.21)												(3.14)										
ln (jobs within 1 km)	-	1.19													1.57									
		(1.80)													(2.73)									
Intersections/road-km	-	-2.00														-0.812	-0.66			-1.38	-0.812	-0.797	-0.758	-0.799
		(-3.55)														(-1.58)	(-1.67)			(-2.51)	(-1.58)	(-1.54)	(-1.45)	(-1.48)
road-km/household	+	0.00165															0.00709							
		(0.137)															(1.98)							
% Detached housing	+	-0.068																-5.77						
		(-1.04)																(-1.98)						
Rooms/housing unit	+	-1.27																-1.02						
		(-1.91)																(-1.31)						
Ratio of on-street bike routes to total road lengths	-																				41.34			
																					(3.00)			
Bike route - binary	-	0.110																				-0.516		
		(0.068)																				(-0.437)		
3-lane arterial roads - binary	+																						1.186	
																							(0.872)	
Ratio of 3-lane arterial road to other road lengths	+	8.72																						12.66
		(0.914)																						(1.31)
R^2		0.844	0.660	0.822	0.825	0.827	0.828	0.831	0.833	0.836	0.837	0.837	0.837	0.839	0.838	0.837	0.838	0.839	0.822	0.824	0.839	0.836	0.837	0.838

Notes:
0.000 variable coefficient
(0.000) t- statistic

ln = natural logarithm of variable

* Variables shown in the shaded column represent those which were used in the final model.

the only **road layout type** variable that was statistically significant in the auto VKT model test runs and was retained for the final model. The coefficient of this variable dropped when intersections/road-kilometre was introduced.[7]

- Variables denoting the presence or extent of **bike routes** in the traffic zone were not statistically significant or resulted in counter-intuitive signs for the coefficients in the auto VKT model.

- The variables showing the ratio of **wide arterial roads** to total roads in the traffic zone was the most robust of the wide arterial road variables. Its t-statistic of 1.42 in the simultaneous regression indicates that confidence in the statistical significance of this variable is relatively high, although somewhat less than the 95% level indicated by a t-statistic of 1.65. It was therefore retained in the final model.

- Including the variable denoting number of **local transit vehicle service hours** in the auto VKT model often resulted in an unexpected sign for the coefficient. However, the variable had the expected sign in the auto ownership model and was retained in the final model.[8]

- **Distance to either a rapid transit station or a GO station** was tested in several different forms, for example, as a binary variable (1 if true, 0 if false) reflecting whether the zone was within a specific distance (e.g., one kilometre) of a GO station or a rapid transit station. The variable that proved the most robust in the auto VKT model results was the distance to either a regional or rapid transit station, in kilometres and was retained for the final model. Including this variable improved overall model fit, and had coefficient values in the order of 0.5.

- **Housing density** measures were statistically significant explanatory variables in initial runs, but decreased in statistical significance and robustness when other variables were added and were, therefore, not included in the auto VKT sub-model. It was retained in the auto ownership sub-model.

- Variables describing the housing in a neighbourhood (e.g., **structural housing type, housing mix, housing size**) generally were not statistically significant in the auto VKT models tested and often resulted in unexpected coefficients for these variables. As a result, they were not retained in the auto VKT sub-model, but were in the auto ownership sub-model.

Auto VKT and auto ownership simultaneous regression analysis

This simultaneous regression analysis used household auto ownership levels, as predicted by a multivariate regression model, as an explanatory variable in the auto VKT multivariate regression model. The household auto VKT and vehicle ownership models resulting from this analysis had R^2 values of 0.84 and 0.88 respectively which indicates a high level of reliability for these models.

The only significant difference between the auto VKT and auto ownership models developed using simple multivariate regression and those developed using simultaneous multivariate regression analyses is, with respect to the variable, vehicles per household. Its coefficient is expected to decrease in the simultaneous regression approach vs. the simple regression analysis. This is due to using predicted (and therefore somewhat less accurate) values of vehicle ownership in simultaneous regression. However, use of the predicted number of vehicles rather than the actual number of vehicles reduced the coefficient only a small amount due to the good fit of the auto ownership sub-model. The exponential form of the vehicles-per-household variable was also tested, but did not increase the predictive strength of the model. Hence, the linear form was retained for simplicity.

Exhibit 16 shows the final household auto ownership and auto VKT model specifications.[9] For each independent variable, the average value,

the range of values and the standard deviation of the observed values are included. Many simultaneous regression model tests were run, but only the final results are shown here. A comparison of the statistical significance and coefficient values for the variables in Exhibit 16 with those in the corresponding model runs of exhibits 14 and 15 shows no significant differences except for two variables in the auto VKT model: vehicle ownership and household size. As noted above, the difference in the vehicle ownership variable is to be expected. The coefficient of the variable denoting household size, with which household vehicle ownership is closely related, increases to compensate.

Transit PKT model

Developing the model of transit passenger-kilometres travelled per household was more of a challenge than developing the auto VKT model. It was often more straightforward to declare an expected sign for a variable in the auto VKT model than for the transit PKT model. This is due to the fact that incentives to increase transit use also increase the possibility of choosing non-motorized travel modes, such as walking or biking, and can reduce the number and length of motorized trips required. A low transit PKT value can indicate a low percentage of total trips being made by transit, even when those transit trips are quite long, or it could indicate that transit is quite well used but the trips are short.

As in the development of the auto VKT and auto ownership models, numerous variable combinations were tested in developing the transit PKT model. Exhibit 17 shows a sample of these individual multivariate regression test models, which use observed values of auto ownership whereas the final simultaneous regression model was calibrated using predicted values of auto ownership. Some observations regarding the performance of individual variables when combined with other variables are discussed.

Exhibit 16
Final Auto Ownership and Auto VKT Models

Auto VKT Equation R^2=0.836; Vehicle Ownership Model R^2=0.878

	Description	Coefficient	t-stat	Study Area Values			
				Average	Minimum	Maximum	Stnd. Dev.
Auto VKT Model	Constant	34.5	3.57				
	Distance to CBD (km)	0.680	9.17	22.1	0.30	76.6	15.0
	Average vehicles per household	15.1	7.62	1.46	0.128	3.77	0.504
	Ln(no. of jobs within 5-km radius)	-3.60	-5.19	10.76	4.87	13.16	1.74
	Land-use mix within 1-km radius	-8.73	-2.79	0.845	0.123	1.000	0.1496
	Ln(avg. no. of people per household)	17.45	5.18	1.006	0	1.504	0.210
	Distance to nearest GO or RT stn (km)	0.534	3.54	3.48	0.046	34.32	4.81
	Average employment income ($1000s)	0.2282	4.64	33.4	14.6	100.9	11.0
	Road type = rural grid (binary)	5.51	3.47	0.237	0	1	n/a
	Intersections/road-km	-1.14	-2.23	2.80	0	7.42	1.36
	Ratio of wide arterials to total road lengths (non-exwy)	12.97	1.42	0.0145	0	0.693	0.0526

	Description	Coefficient	t-stat	Study Area Values			
				Average	Minimum	Maximum	Stnd. Dev.
Vehicle Ownership	Constant	-2.310	-9.22				
	Distance to CBD (km)	0.00448	5.30	22.07	0.30	76.6	15.0
	No. of adults (age 16+) per household	0.433	18.71	2.19	1	3.5	0.340
	Ln(Household income ($))	0.287	11.68	10.8	9.2	12.0	0.394
	Weekday transit vehicle service hours (1-km radius)	-0.00399	-6.52	20.2	0	105.2	21.7
	No. of stores within a 1-km radius	-0.00285	-1.91	4.03	0	49	6.62
	Housing types mix in neighbourhood	-0.1240	-4.31	0.514	0	0.973	0.268
	Ln(housing units, 1-km radius)	-0.0507	-6.88	7.546	1.86	10.29	1.744
	Average dwelling unit size (rooms/unit)	0.0365	40.39	6.422	2.90	9.90	1.382
	Rapid transit station within 1 km (binary)	-0.0539	-2.43	0.152	0	1	-
	Road type = curvilinear (binary)	0.0291	1.80	0.288	0	1	-
	Ratio of bike routes to total road lengths (non-exwy)	-0.252	-2.95	0.0311	0	0.790	0.0778

- The most robust variable was that of the number of **persons per household**. Other indicators of household size, such as adults per household or the natural logarithm of these variables, were also tested, but persons/household provided the best fit and was retained in the final model.

- **Household vehicle ownership** was also robust and statistically significant and therefore retained for the final model. The coefficients of this variable had the expected negative sign: as vehicle ownership increases, household members choose to drive more instead of using transit alternatives. It is especially interesting to see how strong this variable is in the multivariate analysis, as the univariate analysis suggests virtually no relationship between household vehicle ownership and transit PKT. The coefficient values imply that each vehicle a household owns reduces transit use by about four kilometres. Household vehicle ownership was selected for the final PKT model.

- **Employment density**, expressed as the number of jobs within a one-kilometre radius, consistently had a negative sign. It would at first be expected that a higher density of jobs and services in an area would increase transit ridership, but at the same time it reduces trip lengths and encourages non-motorized travel. Hence, the net effect would be a reduction in PKT, and the expected sign on this coefficient is negative, as it is in the final model specification.

- In the same manner as for employment density, an increase in the number of **shopping opportunities** within one kilometre would reduce the number and length of motorized trips needed. Hence the expected sign for the coefficient for the number of grocery stores within one kilometre is negative. This variable was statistically significant and surprisingly robust. Coefficient values were in the order of -0.17 to -0.2. This variable was retained for the final model.

- **Housing density**, expressed as the natural logarithm of the number of units within a one-kilometre radius of the neighbourhood centroid, displayed a positive coefficient in the models tested and was consistently statistically significant. This coincides with the general understanding that a certain threshold housing density needs to be achieved to allow for efficient transit service. Thus, it was retained for the final model.

- The relationship between transit PKT per household and **distance to the CBD** was expressed as a quadratic function by the inclusion of both a linear and a quadratic variable. This pair of variables performed much better than a single linear variable. Both variables were consistently robust and statistically significant and produced the expected sign to replicate the curve in Exhibit 17 and, as a result, were retained for the final model.

- The **number of jobs within a five-kilometre** radius tended not to be a statistically significant variable, even without the inclusion of variables measuring the distance to the CBD. Therefore, this variable was not included in the transit PKT sub-model, although it was retained in the auto VKT sub-model.

- Because the two groups most likely to use transit are youths and the elderly, it was expected that the proportion of the **population under 16 years of age** would be a good predictor of transit use. However, this variable tended not to be statistically significant in the models tested and was not retained in the transit PKT sub-model.

- As would be expected, variables that describe the **level of transit service** available were robust and statistically significant. The variables denoting the distance to the CBD where a rapid transit station was within one kilometre and the distance to the CBD where a GO Transit station was within

Exhibit 17
Transit PKT/Household - Multi-Variate Regression Test Model Runs

Variable	Expected Sign	Model Run																			
		All Varg.	1	2	3	4	5	6	7	8	9	10*	11	12	13	14	15	16	17	18	19	20*
Constant		-9.80 (-2.66)	0.284 (0.293)	0.116 (0.139)	-1.30 (-1.06)	-0.333 (-0.279)	-2.60 (-1.85)	-5.17 (-2.61)	-3.94 (-1.95)	-4.56 (-1.46)	-0.674 (-3.50)	-4.42 (-2.00)	-1.30 (-2.13)	-4.48 (-2.24)	-5.11 (-2.26)	-4.32 (-2.25)	-5.65 (-2.62)	-5.19 (-2.56)	-6.31 (-3.67)	-5.98 (-2.88)	-5.34 (-2.54)	-6.80 (-3.84)
Distance to CBD (km)	+	0.257 (3.36)	-0.0459 (-1.17)	0.126 (2.93)	0.178 (3.31)	0.186 (3.42)	0.269 (5.22)	0.183 (3.41)	0.186 (3.51)	0.194 (3.34)		0.180 (3.40)	-0.0266 (-1.26)	0.186 (3.40)	0.177 (3.34)	0.182 (3.43)	0.213 (4.02)	0.193 (3.52)		0.269 (3.71)	0.197 (3.49)	0.214 (3.99)
Distance to CBD^2 (km^2)	-	-0.00361 (-4.11)	-0.00146 (-2.37)	-0.00288 (-4.65)	-0.00345 (-4.83)	-0.00386 (-4.97)	-0.00478 (-6.52)	-0.00313 (-4.33)	-0.00339 (-4.67)	-0.00340 (-4.67)		-0.00305 (-4.24)		-0.00311 (4.24)	-0.00288 (-4.11)	-0.00306 (-4.24)	-0.0039 (-4.73)	-0.0032 (-4.36)		-0.00372 (-4.98)	-0.00323 (-4.37)	-0.00328 (-4.89)
Persons/household	+	4.40 (1.77)	4.34 (11.7)	5.85 (14.5)	5.74 (14.1)			5.51 (13.2)	5.34 (12.7)	5.32 (12.4)	5.93 (14.5)	5.51 (13.3)	5.98 (14.8)	5.51 (13.3)	5.45 (12.9)	5.70 (10.5)	5.64 (13.7)	5.69 (13.8)	6.16 (15.3)	5.77 (14.0)	5.69 (13.8)	5.70 (13.8)
Vehicles/household (observed)	-	-4.14 (-4.77)		-4.71 (-8.02)	-4.38 (-8.98)	-4.18 (-8.69)	-4.40 (-8.25)	-3.58 (-5.14)	-3.57 (-5.14)	-3.57 (-5.13)	-3.57 (-5.17)	-3.9 (-5.67)	-3.55 (-5.15)	-4.07 (-5.22)	-3.95 (-5.12)	-4.02 (-5.55)	3.82 (-5.50)	-3.79 (-5.56)	-3.49 (-5.10)	-3.72 (-5.47)	-3.77 (-5.50)	-3.76 (-5.51)
Daily bus vehicle service hours, 1 km	+	0.0748 (4.28)			0.0233 (1.59)	0.0267 (1.82)	0.0244 (1.58)	0.0251 (1.72)	0.0325 (2.20)	0.033 (2.21)	0.048 (3.34)	0.0698 (4.23)	0.0427 (2.77)	0.0707 (4.25)	0.0714 (4.22)	0.0691 (4.17)	0.0737 (4.50)	0.0751 (4.58)	0.0558 (3.67)	0.0735 (4.50)	0.0757 (4.58)	0.0747 (4.59)
ln (housing within 1 km)	-	0.76 (3.40)						0.403 (2.47)	0.616 (3.74)	0.601 (3.64)	0.672 (3.88)	0.631 (3.87)	0.676 (4.04)	0.631 (3.87)	0.617 (3.71)	0.647 (3.90)	0.636 (3.93)	0.608 (3.76)	0.911 (4.38)	0.627 (3.88)	0.611 (3.79)	0.709 (3.89)
ln (jobs within 1 km)	-	-6.53 (-2.97)							-5.38 (-2.84)	-0.562 (-2.62)	-0.443 (-2.12)	-0.501 (-2.69)	-0.402 (-2.84)	-0.509 (2.72)	-0.501 (-2.63)	-0.511 (-2.72)	-0.516 (-2.79)	-0.551 (2.98)	-0.412 (-2.26)	-0.586 (-3.10)	-0.550 (-2.95)	-0.62 (-2.77)
No. of stores within 1 km	-	-0.159 (-4.22)									-0.196 (-5.38)	-0.176 (-4.62)	-0.191 (-5.21)	-0.175 (-4.79)	-0.179 (-4.87)	-0.177 (-4.84)	-0.17 (-4.76)	-0.172 (-4.76)	-0.196 (-5.43)	-0.161 (-4.43)	-0.172 (-4.74)	-0.196 (-4.97)
Distance to CBD (km), RT station is within 1 km	+	0.254 (4.12)															0.244 (4.04)	0.248 (4.10)	0.227 (3.76)	0.252 (4.18)	0.250 (4.10)	0.299 (5.13)
Distance to CBD (km), GO station is within 2 km	+	0.0222 (1.40)																0.0217 (1.37)	0.0301 (1.86)	0.0226 (1.44)	0.0218 (1.38)	0.0318 (1.98)
ln (persons/household)	+					14.6 (13.8)																
Adults/household	+	1.69 (0.622)					7.25 (10.5)															
ln (jobs within 5 km)	+	0.286 (0.820)								0.0795 (0.259)	0.21 (-0.913)											
Household emp. income ($1,000)	-	0.00415 (0.336)												0.00467 (0.459)								
% detached housing	-	-0.0137 (-0.532)													-0.00567 (-0.514)							
Rooms/housing unit	-	0.12 (0.521)													0.184 (0.737)							
Housing mix	+	0.234 (0.314)													0.274 (0.339)							
% of population less than 16 yr.. Old	+	2.92 (0.327)														-1.63 (0.536)						
3-lane arterial road - binary	?	1.06 (2.29)																		1.00 (2.20)		
Ratio of total bike routes to total road lengths	+																				0.586 (0.271)	
Bike routes - binary	+	0.498 (1.17)																				0.647 (1.60)
R^2		0.356	0.340	0.297	0.299	0.292	0.290	0.304	0.311	0.312	0.315	0.331	0.310	0.331	0.332	0.331	0.345	0.348	0.322	0.353	0.347	0.349

Notes:
0.000 variable coefficient
(0.000) t- statistic

ln = natural logarithm of variable

* Variables shown in the shaded column represent those which were used in the final model.

two kilometres, also met the criteria and, therefore, were retained for the final model.

- Variables that denote **wide arterial roads** in the traffic zone were statistically significant in the test model runs. However, the expected sign of the coefficient is debatable. Whereas wide arterial roads can increase the speed of transit trips, every transit trip involves wolking, and such roads are expected to decrease the "pedestrian friendliness" of the area. Hence this variable was not included in the final transit PKT model.

- Of variables describing the **extent of bike routes** in the traffic zone, the binary variable simply denoting the presence of any bike route in the traffic zone was found to be the most statistically significant, and was retained in the final model.

- Other variables were also tested: **income variables, number of intersections per road-kilometre, variables indicating road layout type** and variables describing **neighbourhood housing**. These were not retained in the PKT sub-model, as including them often resulted in unexpected signs for the coefficients or they were not statistically significant. However, they were retained in the final model due to good results in the other two sub-models.

The final model specifications can be seen in Exhibit 18.[10] In this model, values of auto ownership as predicted by the vehicle ownership model, were used in the model calibration.

The final transit PKT model uses auto ownership levels predicted using the auto ownership regression model. The overall fit (R^2) of transit PKT model is reduced slightly by using predicted auto ownership levels: from 0.35 to 0.33 but the use of predicted auto ownership was felt to be more consistent with the approach used for the auto VKT model. Given the low R^2 value, the transit PKT model should be observed with a degree of caution.

Model validation and sensitivity

In addition to R^2 values for evaluating a model's goodness of fit, plots of predicted vs. actual values of the dependent variables can provide insight. Exhibit 19 shows such a plot for household auto ownership. It can be seen that, in general, the points fall very close to the diagonal predicted-equals-actual values line, which gives added confidence regarding the model's results.

Exhibit 20 is a plot of predicted vs. actual values for household auto VKT. This plot shows that, in general, the model predicts quite well, with most points lying quite close to the diagonal. There are about a dozen points where the actual weekday auto VKT per household was over 120 kilometres,

Exhibit 18
Final Transit PKT Model

Transit PKT Model R^2=0.329

	Variable	Coefficient	t-stat	Study Area Values			
				Average	Minimum	Maximum	Stnd. Dev.
Transit PKT Model	Constant	-7.03	-2.88				
	Distance to CBD (km)	0.182	3.20	22.1	0.30	76.6	15.0
	Distance to CBD (km), squared	-0.00294	-3.94	n/a	n/a	n/a	n/a
	Predicted avg. vehicles per household	-2.84	-2.57	1.461	0.13	3.77	0.504
	Transit VSH within 1-km radius of centroid	0.7687	4.30	20.2	0	105.2	21.7
	ln(housing units within 1-km radius)	0.870	3.66	7.55	1.86	10.3	1.7
	Avg. household size (persons/household)	5.47	10.66	2.79	1.0	4.5	0.55
	ln(Jobs within 1-km radius of centroid)	-0.496	-2.60	7.40	0	12.3	2.0
	No. of stores within 1 km of zone centroid	-0.165	-4.40	4.03	0	49	6.62
	RT stn within 1 km (binary) x distance to CBD (km)	0.243	3.95	0.930	0	17.9	2.73
	GO stn within 2 km (binary) x distance to CBD (km)	0.023	1.46	5.529	0	46.7	10.83
	Bike routes in neighbourhood (binary)	0.6422	1.56	0.264	0	1.0	-

Exhibit 19
Household Auto Ownership Model Validation: Predicted vs. Actual Values

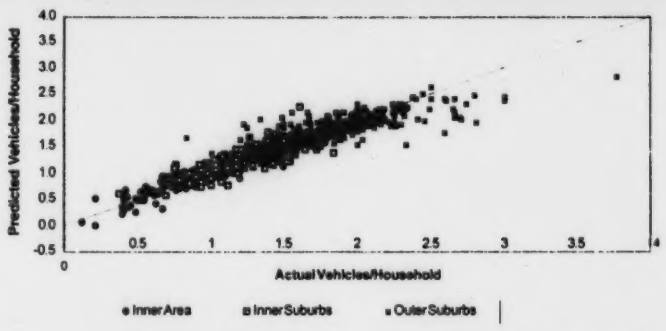


Exhibit 20
Weekday Household Auto VKT Model Validation: Predicted vs. Actual Values

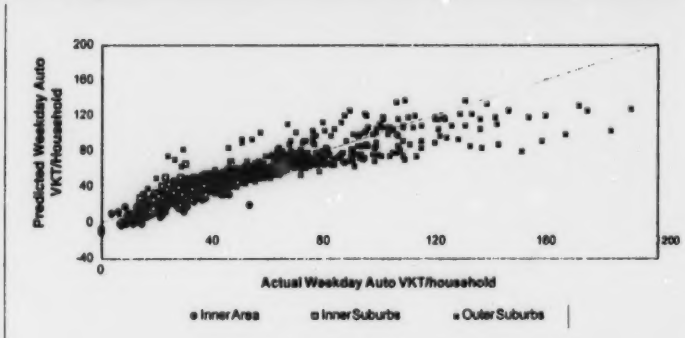
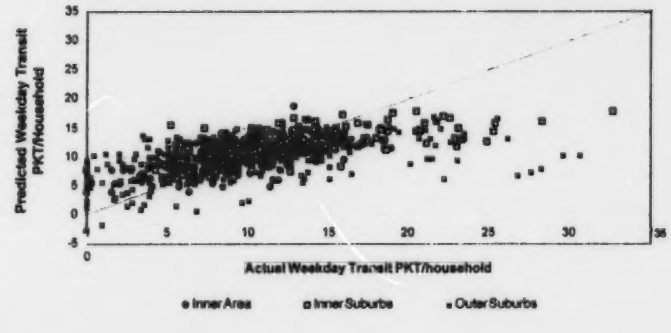


Exhibit 21
Weekday Household Transit PKT Model Validation: Predicted vs. Actual Values



but the model under-predicted the VKT values by 40 VKT or more. These points all represent zones throughout the outer suburbs, and are all 25 kilometres or more from the Toronto CBD. No common characteristics could be detected among these high-travel zones that would improve the model fit.

Exhibit 21 shows predicted vs. actual values for transit PKT per household. As can be expected from the lower R^2 values for this model, the plot does not show as good a fit as the previous two sub-models. Most notably, the model's range of predicted values is significantly less than the range of actual values: actual values of transit PKT per household are as high as 33 PKT, whereas the model predicts no more than 19 PKT. This plot shows that the points representing the inner area zones lie closest to the diagonal, whereas areas in the outer suburbs are not predicted as well by the model. The points with the highest actual values of PKT all represent traffic zones that lie roughly 20 to 40 kilometres from the CBD. Some, but not all, of the traffic zones for which transit PKT values are the most under-predicted are in the general vicinity of GO Transit stations. This points to the difficulty of using a single regression equation to estimate transit travel when a variety of transit services are provided. Perhaps a measure of GO Transit service in addition to GO station proximity would improve the model fit to some extent.

A sensitivity analysis was undertaken of auto VKT and transit PKT per household to changes in the variables incorporated into the models. For this analysis, the values of all variables were held at the study area average values while one explanatory variable was modified across the range of observed values. For this analysis, the auto ownership model was intrinsic to the other two models: changes to auto ownership by changing the value of an explanatory variable would be reflected in the resulting auto VKT or transit PKT for each case.

The impact of the explanatory variables on auto VKT and transit PKT can be seen in exhibits 22 and 23, respectively. The slopes of the resulting lines are included in the graphs. Where the sensitivity analysis results in a curve, the slope is given at the average value of the variable. These exhibits show that the variables with the greatest impact on auto VKT tend to be the locational factors, followed by the socioeconomic ones. Neighbourhood design factors also have an impact, but not to the same extent. The implications of this for urban development planning to reduce transportation GHG emissions are discussed further in Chapter 5.

Another way to evaluate the impacts of each variable is to observe the "impact" of the variable, that is, the contribution the variable makes to the dependent variable, compared to that of all the other variables. Exhibit 24 shows the "impact" of each variable given a 10 per cent increase in the variable from the average value. A broader evaluation of the overall impact of the variable is also provided.

Summary of Multiple Regression Analyses and Impact of Variables

The key variables affecting **auto ownership**, which in turn impact GHG emissions from auto and transit travel, are as follows (listed in approximate order of decreasing importance):

- number of adults in the household;
- household income;
- dwelling unit size;
- distance to the Central Business District; and
- local transit service.

Average dwelling size, the mix of structural housing types, accessibility to shopping, whether there is a rapid transit station within 1 km, and the presence of a curvilinear road layout type also had statistically significant relationship with household vehicle ownership levels.

The key variables affecting **auto travel (VKT)** directly are as follows (again, in approximate order of decreasing explanatory strength):

- distance to the CBD;
- vehicle ownership;
- employment within 5 km;
- people per household;
- land-use mix;
- personal income.

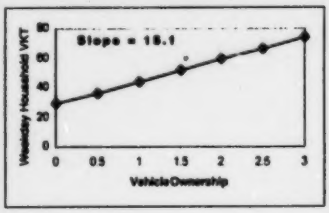
Distance to regional or rapid transit stations, whether the road layout type is rural, and the number of intersections per road-km were also statistically significant variables in explaining auto VKT.

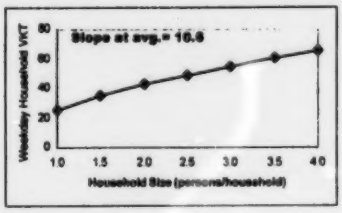
Transit travel (PKT) was directly affected by the following:

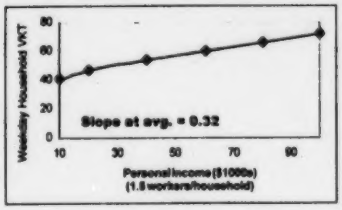
- local transit service is tied with number of people in the household;
- auto ownership;
- distance to the CBD (expressed as a quadratic functional form);
- neighbourhood housing densities;

Exhibit 22
Impact Of Various Factors On Weekday Household Auto VKT*

Socio-Economic Variables







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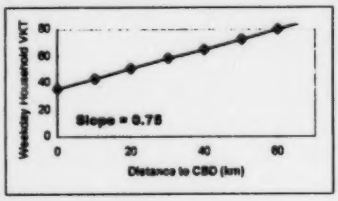
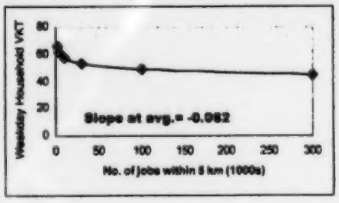
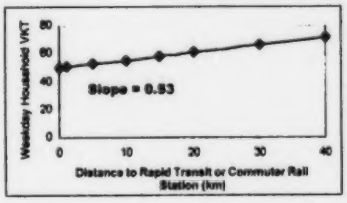
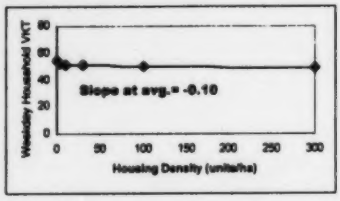
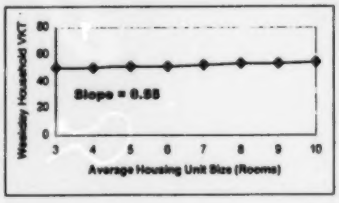


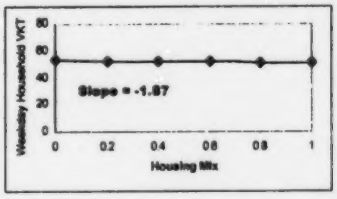


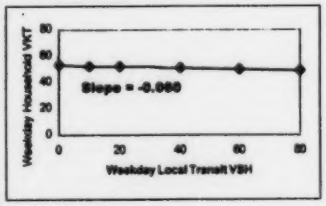


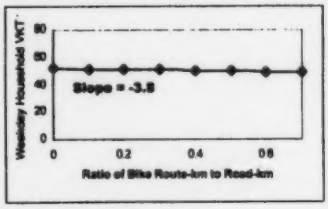
Neighbourhood Variables

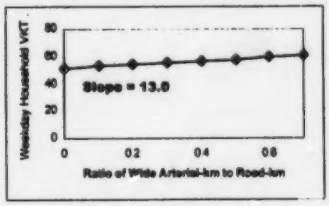


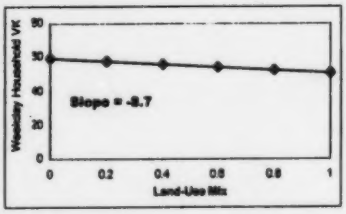


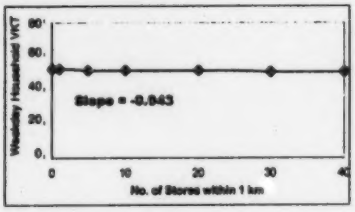








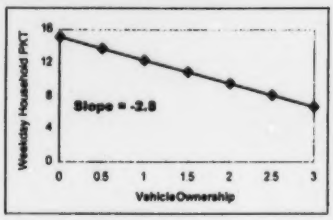


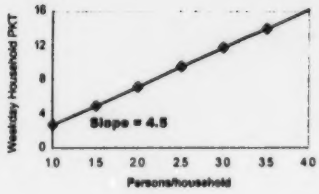


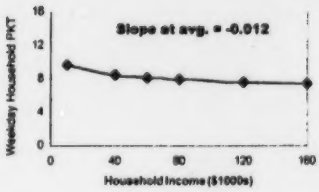
Note: *VKT given variable of interest's coefficient multiplied by the range of its observed values.

Exhibit 23
Impact Of Various Factors On Weekday Household Transit PKT*

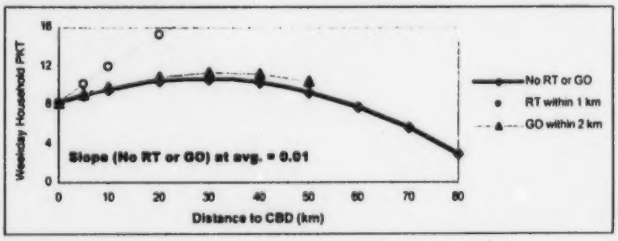
Socio-Economic Variables



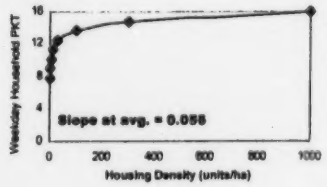


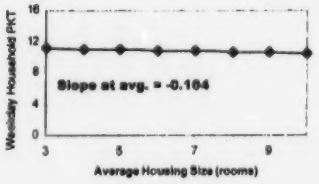


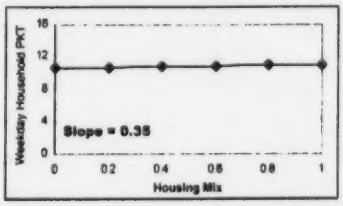
Locational Variables

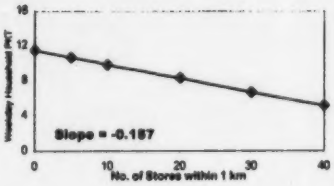


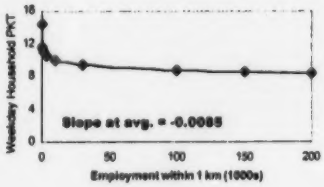
Neighbourhood Variables

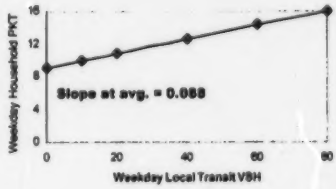












- presense of rapid transit station within one kilometre;
- presence of local shopping and employment opportunities;
- presence of bike routes in the neighbourhood; and
- presence of commuter rail stations within two kilometres.

Development of Emissions Factors

The three main components of greenhouse gases (GHG) are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide is by far the most significant GHG, accounting for over 81 per cent of the impact of anthropogenic GHG emissions from all sources in Canada and approximately 91 per cent from transportation sources. "In general, CO_2 emissions are well-developed for many sources, CH_4 factors are less

Exhibit 24
Impact Of Explanatory Variables on Household Auto VKT, Transit PKT and Vehicle Ownership

	Description	% change in VKT due to 10% increase in variable [1]	Overall impact of Variable [2]
Auto VKT Model	Constant	n/a	n/a
	Distance to CBD (km)	2.90%	★★★
	Average vehicles per household	4.25%	★★★
	Ln(no. of jobs within 5-km radius)[3]	-0.66%	★★
	Land-use mix within 1-km radius	-1.42%	★★
	Ln(avg. no. of people per household)[3]	3.21%	★★★
	Distance to nearest GO or RT stn (km)	0.36%	★
	Average employment income ($1000s)	1.47%	★★
	Road type = rural grid (binary)	0.25%	★
	Intersections/road-km	-0.62%	★
	Ratio of wide arterials to total road length (non-exwy)	0.04%	★

	Description	% change in PKT due to 10% increase in variable [1]	Overall impact of Variable [2]
Transit PKT Model	Constant	n/a	n/a
	Distance to CBD (km)	3.72%	★★
	Distance to CBD (km), squared	-1.33%	★★
	Predicted avg. vehicles per household	-3.84%	★★★
	Transit VSH within 1-km radius of centroid	14.38%	★★★
	ln(housing units within 1-km radius)[3]	0.77%	★
	Avg. household size (persons/household)	14.13%	★★★
	ln(Jobs within 1-km radius of centroid)[3]	-0.44%	★★
	No. of stores within 1 km of zone centroid	-0.62%	★
	RT stn within 1 km (binary) x distance to CBD (km)	0.21%	★★
	GO stn within 2 km (binary) x distance to CBD (km)	0.12%	★
	Bike routes in neighbourhood (binary)	0.16%	★

	Description	% change in veh/hh due to 10% increase in variable [1]	Impact on Auto VKT	Impact on Transit PKT	Overall Impact of Variable [2]
Vehicle Ownership	Constant	n/a	n/a	n/a	n/a
	Distance to CBD (km)	0.65%	0.19%	-1.84%	★★
	No. of adults (age 16+) per household	6.23%	1.81%	-17.66%	★★★
	Ln(Household income ($))[3]	1.79%	0.52%	-5.08%	★★★
	Weekday transit vehicle service hours (1-km radius)	-0.53%	-0.15%	1.50%	★★
	No. of stores within a 1-km radius	-0.08%	-0.02%	0.21%	★
	Housing types mix in neighbourhood	-0.42%	-0.12%	1.18%	★★
	Ln(housing units, 1-km radius)[3]	-0.32%	-0.09%	0.90%	★
	Average dwelling unit size (rooms/unit)	1.54%	0.45%	-4.36%	★★
	Rapid transit station within 1 km (binary)	-0.05%	-0.02%	0.15%	★
	Road type = curvilinear (binary)	0.05%	0.02%	-0.16%	★
	Ratio of bike routes to total road lengths (non-exwy)	-0.05%	-0.01%	0.15%	★

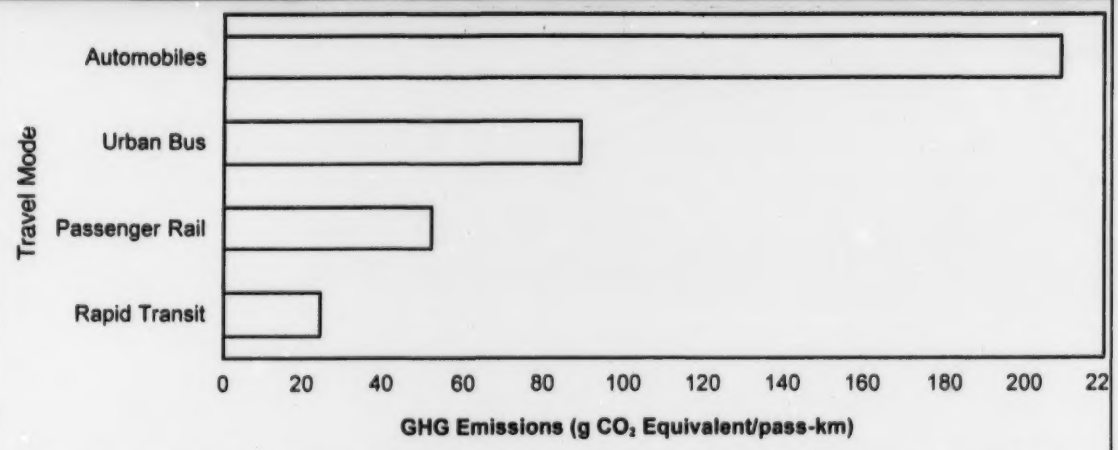
[1] Based on 10% increase of variable value from GTA average, multiplied by coefficient value, and divided by VKT/PKT/vehicle ownership value resulting from average values.
[2] 3 stars - strong impact on dependant variable, 2 stars - medium-strong variable, 1 star - contributes relatively little to dependant variable
[3] The base variable is increased by 10%, rather than the natural logarithm

well-defined, and N_2O factors are often limited and less certain" (Environment Canada, 1997). The emissions factors used in this study represent a combined value for the three primary greenhouse gases and are expressed in CO_2 equivalents. Two sources were used to develop representative GHG factors (IBI Group, 1998).

As shown in Exhibit 25, where GHG emissions are plotted on a passenger-kilometre basis for various travel modes, personal road vehicles are by far the most GHG-intensive modes of personal transportation. When expressed on a passenger-kilometre basis, automobiles emit over eight times as much CO_2 as rapid transit modes and about 2.4 times as much as urban buses. (This value is based on a weighted average of 1.4 passengers per automobile; the model developed in this study predicts auto-driver VKT.)

Auto emission estimates in this study and in the spreadsheet tool are based only on VKT, using an average fuel efficiency for all driving conditions and for all vehicle types. It should be kept in mind

Exhibit 25
GHG Emissions by Passenger Transport Mode



Source: Based on figures derived for the "OECD Environmentally Sustainable Transportation (EST) Study—Québec-Windsor Corridor," Draft report on Phase 2, Prepared for Environment Canada by IBI Group in association with A.K Socio-Technical Consultants (Ottawa) Inc., March 1998.

that in-vehicle idling or stop-and-go congested traffic conditions, for example, result in lower fuel efficiency and greater GHG emissions than uncongested travel. Furthermore, it is well known that different types of vehicles have widely different fuel efficiencies.

The annual emissions as calculated by the spreadsheet tool result from multiplying the daily estimated household travel values by expansion factors that account for expanding weekday travel results to annual travel, underreporting of discretionary trips in the 1996 TTS data set and the amount of CO_2 produced per kilometre travelled.

For auto VKT, the expansion factors were developed as follows.

- The TTS data sample used in this study included households owning a total of 1.92 million vehicles. Taking 18,000 kilometres as the average mileage per vehicle per year (Environment Canada, 1997) results in a total of 34.7 billion annual VKT for the households in the data set.

Applying an underreporting adjustment factor of 1.47 to the total reported vehicular trips, the total weekday VKT for the households in the data set was 88.9 million kilometres. This results in a weekday-to-annual household VKT expansion factor of 390. The fact that the factor is greater than the number of days in a year implies that weekend (and holiday/vacation) trips are longer than weekday trips on average.

- Environment Canada calculates a weighted average fuel efficiency of 11.3 litres per 100 kilometres, and 2,360 grams of CO_2 production per litre of fuel. Therefore, one vehicle-kilometre of auto travel produces 267 grams of CO_2 or 294 grams of GHG in CO_2 equivalents.

- In summary, each unit of VKT predicted by the model is multiplied by 1.46 (under reporting factor) x 390 (weekday to annual trips factor) x 294 grams (CO_2 equivalents per vehicle-kilometre travelled).

The expansion factors for transit PKT were developed as follows.

- The annual transit passenger-kilometre travelled within the Toronto CMA in 1996 is 6.5 billion PKT. Proportional to the number of households in the data set, reduced by

the households in traffic zones that were not statistically significant, this value is 6.4 PKT.

- The total weekday PKT for the households in the traffic zones in the data set was 21,243,000 PKT (after applying an underreporting factor of 1.30). Hence, the appropriate weekday-to-annual household PKT expansion factor is 300. This is less than the number of days in a year, which implies that total weekend travel by transit is less than weekday travel—a reasonable result, given the high prevalence of transit use for work trips.

- Recognizing that the various public transit modes generate varying levels of CO_2 emissions, as show in Exhibit 25, simple regression models were developed using the TTS data to estimate the percentage of transit trips that are by rapid transit, commuter rail, and bus modes. These are based on distances to the nearest commuter rail or rapid transit station, and distance to the CBD (endnote 11). For simplicity, it is assumed that the percentage of trips is proportional to the PKT percentages. The appropriate emissions factor for each transit mode -22 g CO_2/PKT for subway, 47 g CO_2/PKT for commuter rail and 81 g CO_2/PKT for buses—is then applied to the transit PKT values by mode.

- In summary, each unit of VKT predicted by the model and further refined by transit mode is multiplied by 1.30 (underreporting factor) x 300 (weekday to annual trips factor) x appropriate CO_2 equivalents per passenger-km travelled.

Spreadsheet Tool for Evaluating Neighbourhoods

The main purpose of this study is to develop a user-friendly tool to facilitate use of the final model, the development of which was discussed in this chapter, for the evaluation of GHG emissions for any neighbourhood, as described by its community design, locational and socioeconomic characteristics. The spreadsheet tool was used in evaluating the nine different neighbourhood scenarios in Chapter 5.

The tool is stored as a file, "tool.xls" that can be opened as a regular spreadsheet file in Microsoft Excel 7.0. When the file is opened, the user sees a form, that introduces the spreadsheet tool. The remaining parts of the tool are as follows:

- The **Main Menu** worksheet, which provides command buttons by which the user can access a form to change input variables, to print or examine the model results, or to save or exit the tool. This worksheet also includes a "scenario manager," by which the user can choose one of the nine built-in neighbourhood scenarios discussed in Chapter 5, or a scenario created and stored by the user.

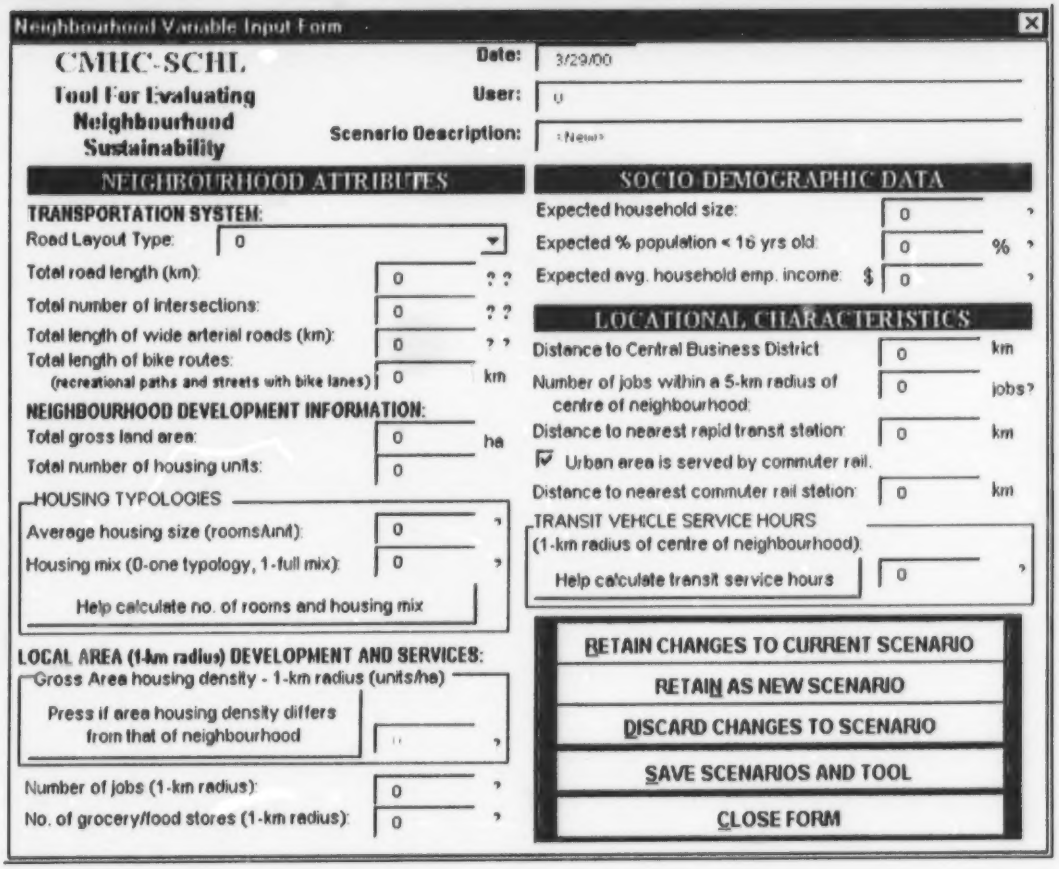
- A **Variable Input** form (shown in Exhibit 26), where the user inputs the neighbourhood variables, including neighbourhood attributes and locational and socioeconomic data.

- A **Model Results** worksheet, which summarizes the scenario details, the model parameters and the model results, together with annual GHG emissions by auto and by transit for an average household in the neighbourhood.

The average annual GHG emissions per household are also presented in graphical form as a small chart.

Further instructions for using the tool are included as Appendix A.

Exhibit 26
Neighbourhood Variable Input Form


Neighbourhood Variable Input Form
CMHC-SCHL
Tool For Evaluating Neighbourhood Sustainability
Date: 3/29/00
User: 0
Scenario Description: <New>
NEIGHBOURHOOD ATTRIBUTES
TRANSPORTATION SYSTEM:
Road Layout Type: 0
Total road length (km): 0
Total number of intersections: 0
Total length of wide arterial roads (km): 0
Total length of bike routes: (recreational paths and streets with bike lanes) 0 km
NEIGHBOURHOOD DEVELOPMENT INFORMATION:
Total gross land area: 0 ha
Total number of housing units: 0
HOUSING TYPOLOGIES
Average housing size (rooms/unit): 0
Housing mix (0-one typology, 1-full mix): 0
Help calculate no. of rooms and housing mix
LOCAL AREA (1-km radius) DEVELOPMENT AND SERVICES:
Gross Area housing density - 1-km radius (units/ha)
Press if area housing density differs from that of neighbourhood
Number of jobs (1-km radius): 0
No. of grocery/food stores (1-km radius): 0
SOCIO DEMOGRAPHIC DATA
Expected household size: 0
Expected % population < 16 yrs old: 0 %
Expected avg. household emp. income: $ 0
LOCATIONAL CHARACTERISTICS
Distance to Central Business District: 0 km
Number of jobs within a 5-km radius of centre of neighbourhood: 0 jobs
Distance to nearest rapid transit station: 0 km
Urban area is served by commuter rail.
Distance to nearest commuter rail station: 0 km
TRANSIT VEHICLE SERVICE HOURS (1-km radius of centre of neighbourhood)
Help calculate transit service hours 0
RETAIN CHANGES TO CURRENT SCENARIO
RETAIN AS NEW SCENARIO
DISCARD CHANGES TO SCENARIO
SAVE SCENARIOS AND TOOL
CLOSE FORM

5. DEVELOPMENT OF NEIGHBOURHOODS AND URBAN CONTEXT SCENARIOS

This section describes three neighbourhood-type scenarios and three urban-context scenarios that are evaluated according to emission results obtained by the model. By estimating the energy consumption and emissions for each neighbourhood type while holding location constant, it is possible to gain insights into the impacts of different neighbourhood designs. By varying the locational context, one can also see the impacts on GHG emissions.

Exhibit 27 provides a summary of the statistics for each scenario. A description of the individual neighbourhood scenarios follows.

Neighbourhood Context Scenarios

A description of three possible neighbourhoods that could achieve this purpose is presented below.

Exhibit 27
Summary Statistics for Proposed Neighbourhood/Urban Context Scenarios

Independent Variables		Study Area Average	A. Inner Area 1A	A. Inner Area 2A	A. Inner Area 3A	B. Inner Suburbs 1B	B. Inner Suburbs 2B	B. Inner Suburbs 3B	C. Outer Suburbs 1C	C. Outer Suburbs 2C	C. Outer Suburbs 3C
SOCIO-DEMOGRAPHIC VARIABLES											
Average household size (persons/household)		2.792	2.792	2.792	2.792	2.792	2.792	2.792	2.792	2.792	2.792
% population under 16 years old		21.0%	21.0%	21.0%	21.0%	21.0%	21.0%	21.0%	21.0%	21.0%	21.0%
Average adults per household		2.206	2.206	2.206	2.206	2.206	2.206	2.206	2.206	2.206	2.206
Average employment income		$34,290	$34,290	$34,290	$34,290	$34,290	$34,290	$34,290	$34,290	$34,290	$34,290
Average household employment income		$51,430	$51,430	$51,430	$51,430	$51,430	$51,430	$51,430	$51,430	$51,430	$51,430
NEIGHBOURHOOD ATTRIBUTES											
Road layout type			Random Curv.	Mixed Grid/Curv	Rect. Grid	Random Curv.	Mixed Grid/Curv	Rect. Grid	Random Curv.	Mixed Grid/Curv	Rect. Grid
Intersections per road-km			3.0	5.0	5.2	3.0	5.0	5.2	3.0	5.0	5.2
Bike route			0.0	0.0	0.5	0.0	0.0	0.5	0.0	0.0	0.5
Wide arterial roads			0.8	0.4	0.0	0.8	0.4	0.0	0.8	0.4	0.0
Total Land Area (ha)			45	41.5	32.2	45	41.5	32.2	45	41.5	32.2
Residential			32	32	20	32	32	20	32	32	20
Employment			0	2.3	2.7	0	2.3	2.7	0	2.3	2.7
Community facilities			0	0	2	0	0	2	0	0	2
Retail			0	0	1.1	0	0	1.1	0	0	1.1
Park			13	7.2	6.4	13	7.2	6.4	13	7.2	6.4
Total Housing Units			185	900	1400	185	900	1400	185	900	1400
Structural Housing Type Profile (Percentage of total units)	AVG. ROOMS										
Fully-detached	8.5	54.7%	100%	33%	8%	100%	33%	8%	100%	33%	8%
Semi-detached	7	19.2%	0%	13%	16%	0%	13%	16%	0%	13%	16%
Town/row house	6	9.3%	0%	13%	21%	0%	13%	21%	0%	13%	21%
Low-rise apartments	5	7.6%	0%	20%	18%	0%	20%	18%	0%	20%	18%
High-rise apartments	3.5	9.2%	0%	20%	39%	0%	20%	39%	0%	20%	39%
Housing types mix		0.514	-	0.961	0.915	-	0.961	0.915	-	0.961	0.915
Average unit size (no. of rooms)		6.44	8.5	6.3	5.2	8.5	6.3	5.2	8.5	6.3	5.2
Housing density (housing units/ha)		14.81	3.667	21.687	43.478	3.667	21.687	43.478	3.667	21.687	43.478
Employment (neighbourhood)		-	0	250	750	0	250	750	0	250	750
Employment (1-km radius, based on above)		7,157	0	1,893	7,317	0	1,893	7,317	0	1,893	7,317
Land-use mix		0.6448	-	0.6253	0.8315	-	0.6253	0.8315	-	0.6253	0.8315
Shopping index (grocery stores within 1 km)		4.034	0	3	15	0	3	15	0	3	15
LOCATIONAL CHARACTERISTICS											
Distance to CBD (km)		22.07	5	5	5	10	10	10	30	30	30
Number of jobs within 5 km (1000's)		113.3	400	400	400	120	120	120	60	60	60
Distance to nearest rapid transit station		11.72	1	1	1	2	2	2	10	10	10
Distance to nearest GO station		4.12	5	5	5	5	5	5	2	2	2
Transit vehicle service hours within 1 km		20.20	35	45	50	25	30	35	5	10	15
PERFORMANCE INDICATORS											
Average vehicles/household		1.46	1.52	1.14	0.98	1.83	1.27	1.12	1.80	1.44	1.29
Average weekday auto VKT/household *		74.7	58.5	38.4	28.5	73.2	51.6	43.7	100.6	79.0	71.1
Average weekday transit PKT/household *		13.0	19.3	18.2	17.4	17.2	15.5	14.7	17.1	15.4	14.7
Average annual GHG emissions per household (kg CO_2 equivalent)		8,800	7,000	4,500	3,600	8,700	6,100	5,200	11,800	9,300	8,400

* adjusted for under-reporting of trips in TTS

LEGEND:
Neighbourhood 1: Suburban-Type Development
Neighbourhood 2: Medium-Density Development
Nieghbourhood 3: Neo-traditional Development

Conventional suburban-type development (neighbourhood type 1)

This neighbourhood concept has been developed to reflect the characteristics of modern suburban developments. These neighbourhoods are typically low-density, single-use, residential developments with street patterns consisting of curves and cul-de-sacs extending out to wide auto-oriented arterial roadways.

Exhibit 28 illustrates the typical housing types that would be constructed in these neighbourhoods. Exhibit 29 provides a schematic diagram of a typical low-density suburban development, which corresponds to the statistics for neighbourhood scenario 1. The conceptual neighbourhood scenario was created from an actual site plan for a development recently established in York Region, north of Toronto.

Exhibit 28
Typical Housing Types for Neighbourhood Type 1

The key design features of this neighbourhood are as follows[12]:

- single use development with no on-site employment or commercial amenities;
- large lots, typically greater than 25 metres width, resulting in a low overall gross density (3.6 units/hectare);
- discontinuous streets with no continuous streets through the site and a complete absence of breaks between lots for pedestrians (Note: walking distance from the cul-de-sac in the lower left hand corner of the site to the only nearby arterial at the top of the site is approximately 600 metres, well beyond the maximum of 400 metres most transit users are willing to walk to a bus stop);
- wide two-lane road cross section (9.5-metre pavement width), which allows for parking on both sides of the street; and
- inward orientation of housing (e.g., the backs of the houses would face the arterial roadway).

Medium-density development (neighbourhood type 2)

This neighbourhood concept reflects a balance between modern suburban development and the more traditional high-density, mixed-use development found in neo-traditional neighbourhoods. As shown in Exhibit 27, this neighbourhood would have a higher number of persons than jobs, but there would be significant opportunities for self-containment in terms of local employment. Residential density of this neighbourhood would be approximately 21 dwelling units per hectare.

Exhibit 30 illustrates the typical housing typologies while Exhibit 31 provides a graphical representation of neighbourhood type 2. Some of the key design features of this neighbourhood are as follows:

- a mix of single-detached houses, low-rise townhouses and mid-rise (less than six floors) residential apartment buildings;
- medium-sized lots, ranging from 10 to 15 metres in width;
- mainly curvilinear streets, but with some continuity and connectivity for transit vehicles and pedestrians;

Exhibit 29
Neighbourhood 1—Conventional Suburban Development

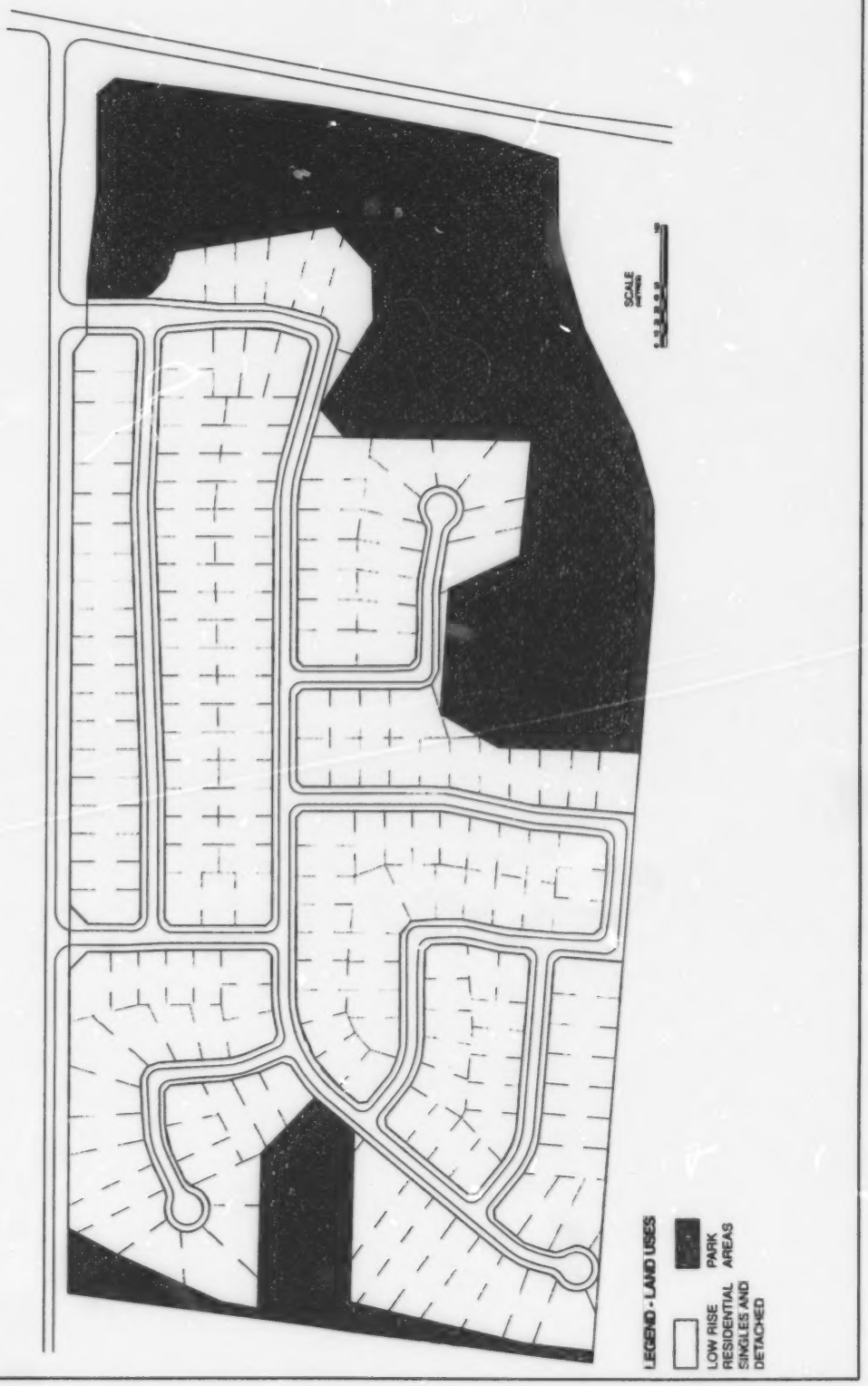
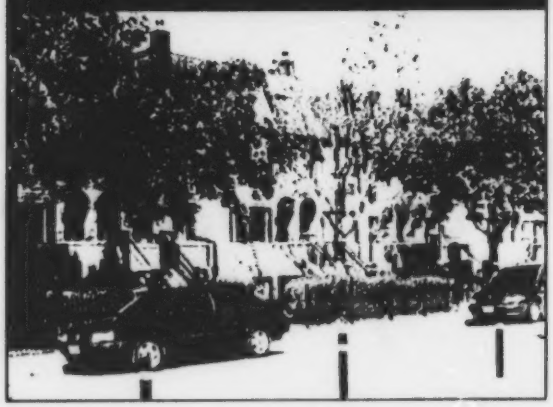


Exhibit 30
Typical Housing Types for Neighbourhood Type 2



- primarily auto-oriented streets with some pedestrian-scale features such as boulevards and sidewalks;
- unrestricted on-site residential parking, but restricted on-street parking on the primary roadways;
- some on-site employment; and
- a small amount of ancillary retail (e.g., convenience store/market).

Neo-traditional development (neighbourhood type 3)

There have been many attempts to define "neo-traditional development" but, generally, all these definitions embody the following principles:

- a return to the grid circulation system, or at least provision of more direct connections between any two points within the community;
- a return to communities that are more "friendly" to pedestrians and bicyclists, and less dominated by the appetite of the car for space and speed; and
- an increase in the viability of transit as an alternative to the private automobile (Bookout, 1992).

In the scenarios involving neighbourhood type 3, all attempts were made to assign values to each variable that were reflective of neo-traditional planning, but also those reflective of high-density urban development. In contrast to neighbourhood types 1 and 2, there is a higher density of both jobs and persons thereby increasing the jobs/worker balance. The overall residential density of neighbourhood type 3 is 43 units/hectare. This density is typically found only within the core of major urban areas.

Exhibit 33 provides a representation of the site plan for neighbourhood type 3. This overall neighbourhood plan was derived from the site plan for the Greenwood Racetrack development, currently under construction in the Beaches area of Toronto. Some modifications to the actual site plan were made for this study, namely, the addition of highrise apartment buildings and the addition of employment areas. Generally, the

Exhibit 32
Typical Housing Types for Neighbourhood Type 3

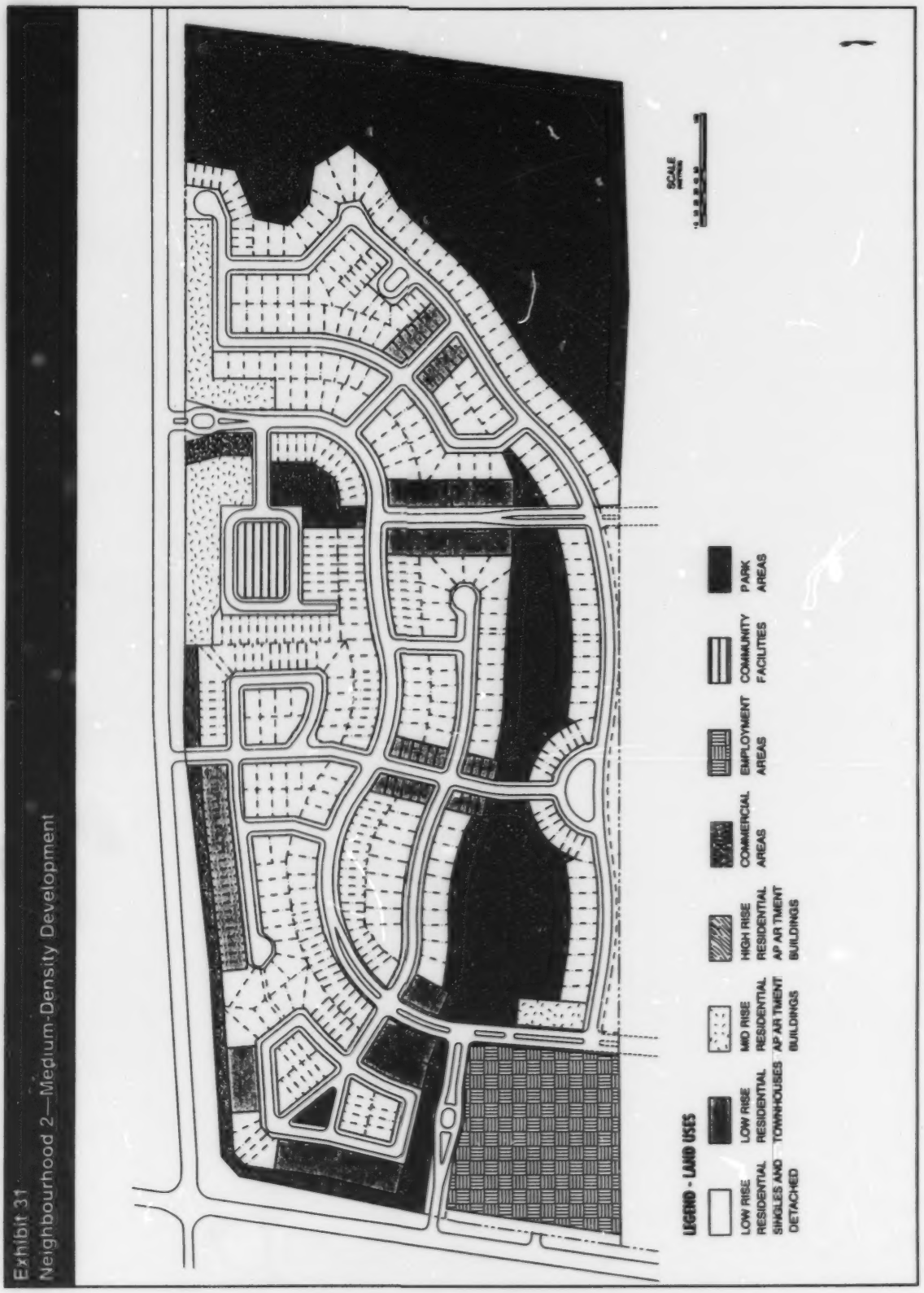
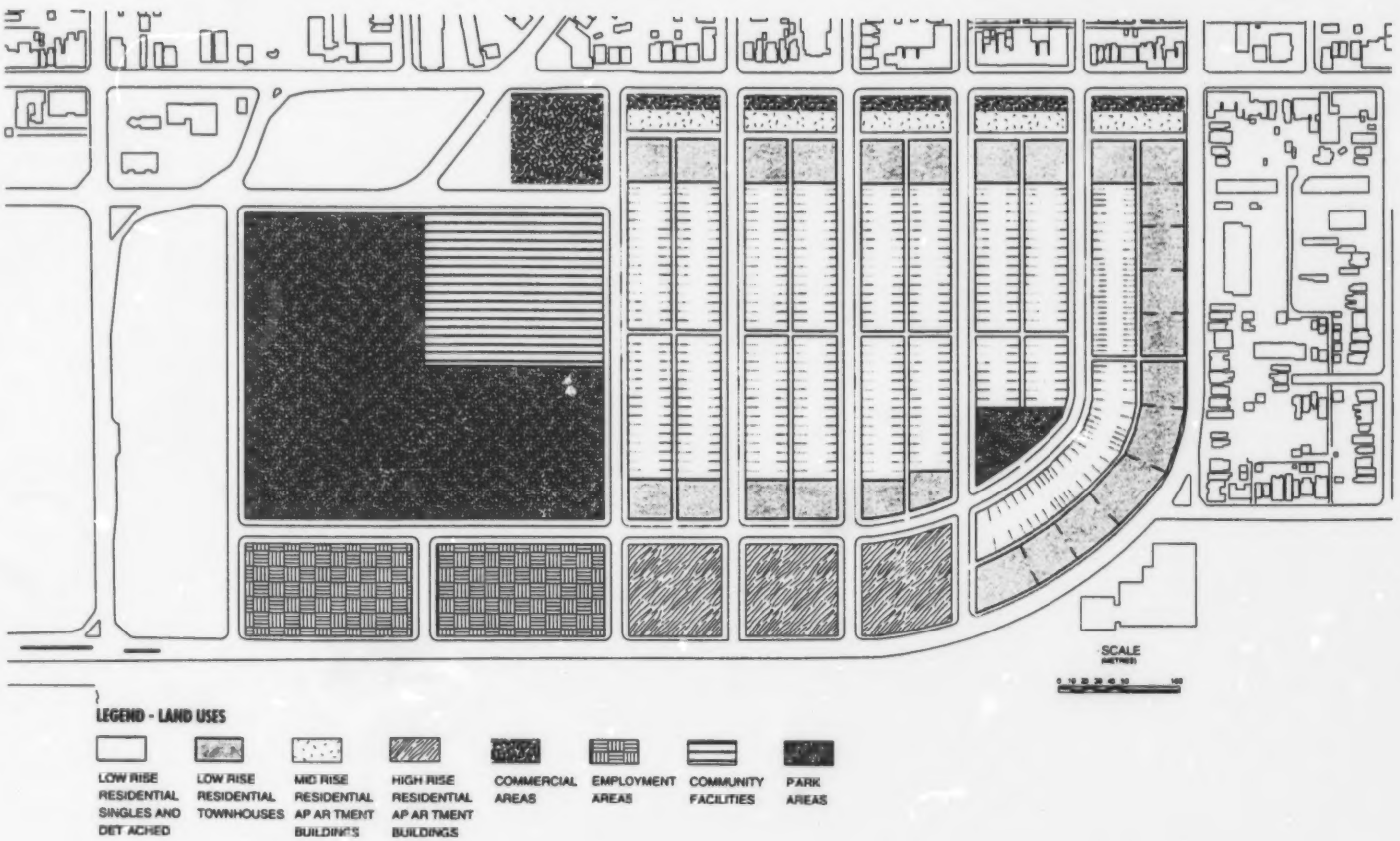


Exhibit 31
Neighbourhood 2—Medium-Density Development

Exhibit 33
Neighbourhood 3—Neo-Traditional Development



overall road and building layouts were retained. The key features of the neighbourhood are as follows:

- a mix of housing typologies including apartment buildings and closely spaced housing units;
- narrow, closely spaced lots preferably with lane access to back-alley parking for the semi-detached houses;
- a grid pattern of closely spaced streets with full accessibility to adjacent arterials;
- narrow streets with wide sidewalks and a "pedestrian focus"; and
- on-site employment and ancillary uses. Non-residential uses include a grocery store, retail shops (ideally at grade and below the highrise apartments), a school and an area designated for employment uses (ideally, office or other employment consistent with the employment characteristics of nearby residential dwellers).

Urban Context Scenarios

The urban context scenarios are defined largely to allow comparison of each neighbourhood concept in different urban settings. Up to this point in this report, the urban context scenarios have been defined on the basis of planning districts as shown previously in Exhibit 1, largely for the purpose of displaying and discussing the empirical analysis. With the model structure developed for this study, it is possible to define the urban context scenarios through the use of four primary locational variables:

- distance to CBD;
- number of jobs within five kilometres;
- distance to nearest rapid transit station; and
- distance to nearest regional transit (e.g., GO) station.

In addition to these factors, local transit vehicle service hours vary by urban context, as this variable is understood to be a function of both urban context and neighbourhood design. This variable takes on values reflecting similar neighbourhoods in the GTA.

A description of the three urban context scenarios is provided below.

Inner area (location A)

As shown on Exhibit 27, the inner area scenario is characterized as being about five kilometres from the CBD and about one kilometre from the nearest rapid transit station. Within the inner core, there are no GO stations (with the exception of Union Station) and, therefore, this variable has been assigned a relatively high value (five kilometres). Most neighbourhoods within the inner area are located close to major employment areas and as a result, the inner area scenario has been assigned a high value for the number of jobs within five kilometres.

Inner suburbs (location B)

The inner suburbs scenario generally was developed to be representative of the areas within the City of Toronto but outside of the inner area. On average, the inner suburbs are about 10 kilometres from the CBD. Neighbourhoods within the inner suburbs are often within reasonable walking distance or a short driving distance to either a subway station or a GO rail station, and the distances assigned to these variables reflect this. Compared to the inner area, there would be fewer jobs within five kilometres.

Outer suburbs (location C)

The outer suburbs definition includes areas within the regions of Durham, York, Peel and Halton. At a minimum these areas are 15 kilometres from the CBD by straight-line distance. Areas typical of the outer suburbs, for example Brampton and Markham, are 25 or more kilometres from the CBD. A value of 30 kilometres from the CBD

has been adopted for urban context scenario C. Many of the neighbourhoods in the outer suburbs are served by GO rail. Therefore, a low value has been assigned to the variable denoting distance to GO rail.

Evaluation of Scenarios

Exhibit 34 shows graphically the annual GHG emissions for the nine different neighbourhoods as predicted by the model. This plot makes it easy to see that both the urban context and the neighbourhood design context have a significant effect on CO_2 emissions from travel.

It is valuable to note that the neighbouhood's location has a stronger influence than the neighbourhood design variables. The impact of changing the neighbourhood context from the outer suburbs to the inner area is a decrease in GHG emissions of 36 to 60 per cent for the three neighbourhood scenarios. But the impact on GHG emissions is less dramatic when the location is held constant and the neighbourhood design features are changed. This results in GHG reductions ranging from 24 to 50 per cent. Households in neighbourhoods with neo-traditional design features located in the outer suburbs generate about 20 per cent more annual GHG emissions from travel than households in neighbourhoods with single-use suburban-type designs located in the inner area of the city.

Where neighbourhood variables play the largest role is in terms of vehicle ownership. Exhibit 35 plots the vehicle ownership levels for the different scenarios. Here, the variation in vehicle ownership levels is less across different urban contexts than it is across the different neighbourhood designs. The impact of keeping the locational variables the same and creating less sustainable neighbourhoods is to increase vehicle ownership 30 to 35 per cent, whereas changing the neighbourhood context from the inner area to the outer suburbs increases auto ownership about 15 to 25 per cent for these test neighbourhoods.

Exhibit 34
Neighbourhood Scenarios Evaluation: Annual GHG Travel Emissions/Household

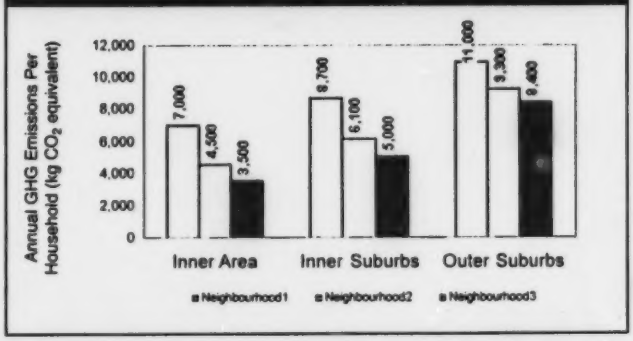
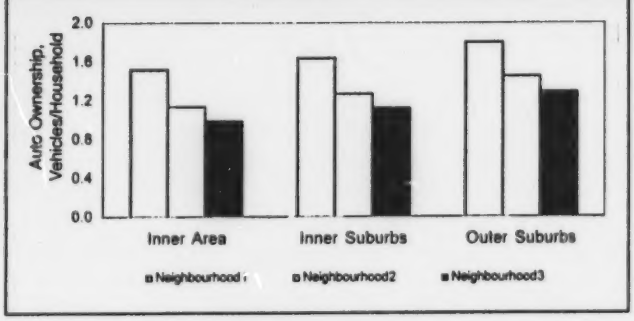


Exhibit 35
Neighbourhood Scenarios Evaluation: Household Vehicle Ownership



6. CONCLUSIONS

Key Results

This study has resulted in the development of a multivariate regression model and a spreadsheet tool for estimating GHG emissions from urban transportation. Specifically, it distinguishes among various neighbourhood designs in terms of their propensity to generate GHG emissions from personal travel when located at different distances from the centre of an urban area.

The model is made up of three sub-models that estimate vehicle ownership, auto travel and transit travel, respectively, for an average household in the neighbourhood. The auto ownership and auto vehicle-kilometre models had impressively strong predictive power with an R^2 of 0.88 and 0.84, respectively. These high R^2 values indicate that the variables selected for these models account for most of the influence on auto usage and ownership. The transit passenger-kilometre model was less robust and had a moderate R^2 of 0.35.

The model development process showed that whereas some variables were strong predictors for one sub-model, the same variables were not statistically significant for other sub-models. For example, some aspects of neighbourhood location, design or socioeconomics affect GHG emissions only indirectly by affecting vehicle ownership, which was found to be a key variable influencing GHG emissions in terms of both auto and transit travel.

The features of three hypothetical neighbourhood designs, with three different urban contexts (inner area, inner suburbs and outer suburbs) were tested using the spreadsheet tool. Of the nine scenarios tested, the neighbourhood located in the inner urban area and with the most compact, mixed-use, pedestrian-oriented design had the lowest rate of GHG emissions (3,500 kilogram CO_2 equivalent annually per household). The neighbourhood located in the outer suburbs and with the most conventional suburban design had the highest rate of GHG emissions (11,000 kilogram CO_2 equivalent annually per household).

It was found that, although neighbourhood design influenced travel decisions, the magnitude of the impacts of changes to neighbourhood design variables are not as great as those of changes to locational factors or the socioeconomic make-up of the neighbourhood.

This suggests that the "macro" urban structure is more important than the "micro" neighbourhood design in reducing greenhouse gas emissions from auto and transit travel by neighbourhood residents. That is, in-fill development to increase resident population in inner areas and inner suburbs is more effective than greenfield development in moderating the growth of GHG emissions, even if the new greenfield neighbourhood is neo-traditional rather than typical conventional suburban in design. However, neighbourhood design is also a significant determinant of GHG emissions, and the spreadsheet models produced by this study provide a useful tool for planners and developers for estimating the GHG emission implications of both neighbourhood design and the broader-scale urban structure considerations of in-fill vs. greenfields development.

Users of the tool should note that the regression model used by the tool was developed based on data from the Toronto Census Metropolitan Area and has not been tested or validated for other Canadian cities. The tool is capable of establishing the relative differences of two or more neighbourhoods in any large metropolitan area. The absolute GHG estimate may not be exact.

Recommendations for Further Research

In carrying out this study, a number of suggestions arose for further work on the

topic of modelling GHG emissions from travel based on neighbourhood attributes.

First, a more robust transit model may arise through modelling various transit services separately, by modelling transit use simply as the percentage of total travel, or by choosing a different model form than a regression equation. Because transit is used differently by different people (e.g., youth and the elderly use transit more often than those of other age cohorts), the transit model would benefit from predicting transit travel at a more disaggregate level.

Second, additional neighbourhood design variables (e.g., parking, traffic calming,, streetscapes) may have an important impact on household travel behaviour. Many of these are difficult to quantify or it was beyond the scope of the study to assemble comprehensive data for these variables. Quantifying and measuring the impact of these variables is a worthwhile task for further investigation.

Third, a more thorough analysis of the emissions factors for different kinds of travel and of weekday-to-annual expansion factors may be insightful in evaluating neighbourhood sustainability in terms of gas emissions more precisely.

ENDNOTES

1 A note of caution regarding use of TTS travel data. The data set is based on trips reported by the households interviewed in the study. Because the household member being interviewed may not be aware of all trips made by other household members, there is a known underreporting bias, which becomes more problematic in reporting discretionary (i.e., non-work/non-school) trips, which are often made during off-peak travel times. The analyses described in chapters 3 and 4 are based on reported trips. Correction factors to mitigate this bias are introduced in Chapter 4, and the remainder of the report and the spreadsheet tool incorporate these factors.

2 This report frequently makes reference to R^2 values. R^2 is a statistical measure of goodness of fit, ranging from 0 when there appears to be no relationship whatsoever between the dependent and independent variable(s) as described by the functional form, such as a straight line, to 1 when the relationship between the variables is explained perfectly.

3 It should be noted that this includes income directly from employment only, and would exclude that generated by government payments, investments, inheritances, etc.

4 The central business district (CBD) or downtown core is generally defined as the area bounded by University Avenue, Dundas Street, Jarvis Street and Front Street. It comprises an area of 1.2 km2.

5 Grocery stores listed in the yellow pages do not generally include convenience stores. However, a large number of "corner market" stores were listed.

6 The relationship between the distance to the CBD and employment accessibility within five kilometres in predicting auto VKT is striking. It implies that one of the reasons the distance to the CBD is such a strong variable is that households are attracted to the high number of jobs in the CBD. However, as the number of jobs in the vicinity of the home neighbourhood increases, there is a reduced probability that the household will need to travel to the CBD. Nonetheless, the fact that the distance to the CBD remains a strong variable even together with job accessibility within five kilometres as a variable indicates that the CBD continues to draw trips from the home neighbourhood. The area within a five-kilometre radius of the CBD contains approximately 500,000 jobs, or almost one fifth of the jobs in the GTA.

7 This indicates that part of the reason why travel behaviour is different in rural grid areas is the decreased connectivity of the road network related to the number of intersections/road-kilometre. However, the fact that the variable still remains strong shows it is also a proxy for other elements of rural life that lend themselves to greater automobile travel (e.g., greater isolation, longer travel distances, no transit service).

8 As transit service increases, auto ownership decreases which, consequently, does affect auto VKT, albeit to a smaller degree. This finding implies that people are more reluctant to use alternative modes of transit when they have a personal vehicle already, but they are less likely to have high auto ownership levels if more transit service is available in the local area.

9 These model specifications are based on predicting values of auto VKT that coincide with the values of daily VKT in the data set, which are based on *reported* trips, and these are known to be underestimated. To compensate for this, the spreadsheet tool

includes a factor of 1.47 for auto VKT based on comparisons of TTS-assigned traffic with actual traffic levels in Toronto, in calculating GHG emissions from the estimated VKT levels produced by the models, as described further below.

10 Again, it is noted that these coefficients are based on predicted values of transit PKT that coincide with the values of daily PKT in the data set, which are based on *reported* trips, known to be underestimated. To compensate for this, the spreadsheet tool includes a factor of 1.30, based on comparisons of TTS-assigned traffic with actual traffic levels in Toronto, in calculating GHG emissions from the estimated PKT levels produced by the models, as described further below.

11 The equations for estimating the percentage of trips by mode are as follows:

% trips by rapid rail = 0.6061 - 0.1525 * ln (distance to nearest rapid rail station, km) (R^2 = 70%)

% trips by GO transit = -0.00932 (Distance to nearest GO station) + 0.00521 (Distance to CBD, km) (R^2 = 28%)

% trips by bus = 100% - % trips by rapid rail - % trips by GO transit

12 Only those features that are quantifiable (e.g., density, land use mix, street pattern) are represented in the model.

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Appendix A:

User's Guide for Spreadsheet Tool

A.1 Introduction

This section provides a description of how to use the spreadsheet tool for estimating greenhouse gases from urban travel by inputting neighbourhood variables. Given the nature of urban travel behaviour and the wide variety of neighbourhoods encountered in an area, the results obtained using this tool should be observed with a degree of caution. The user should also note that the regression model used by the tool was developed based on data in the Toronto Census Metropolitan Area and has not been tested or validated for other Canadian cities. It is the opinion of the researchers involved that the tool is capable of establishing the relative differences between two or more neighbourhoods in any large metropolitan area, although the absolute greenhouse gas estimates may not be exact.

IBI Group recognizes that this tool could be used for a number of purposes by a wide variety of users. IBI Group does not, however, assume responsibility for how the user applies and uses the results of the tool, as this is beyond its control. The user of the tool is encouraged to read the main report documenting the research undertaken before interpreting the model results.

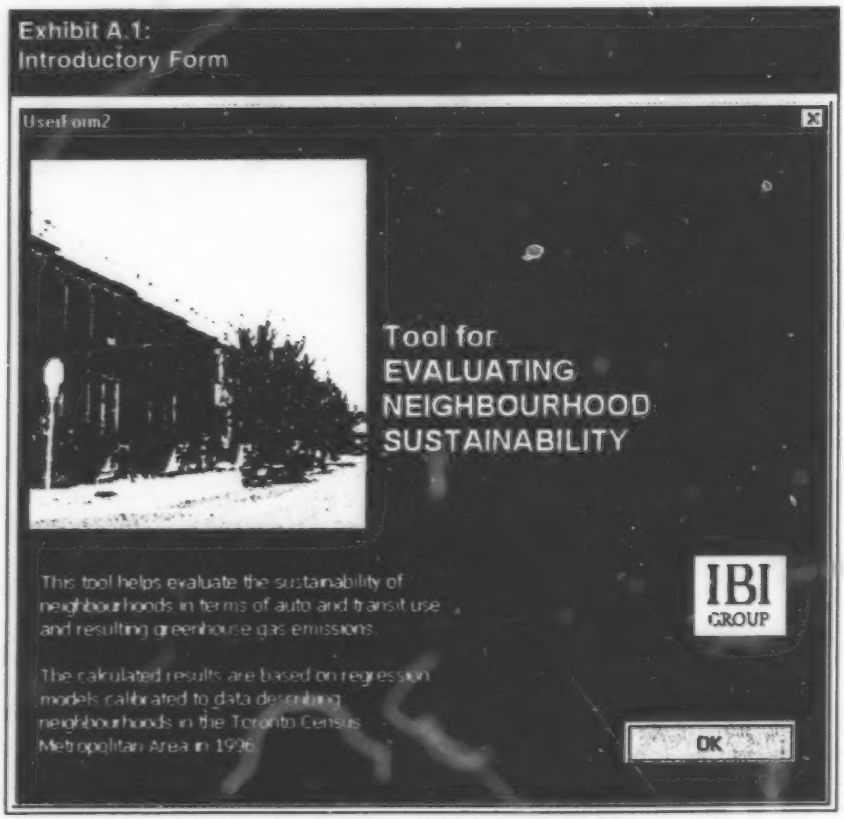
A.2 Opening the Tool

The spreadsheet tool is designed as a file, "tool.xls," that can be opened as a regular spreadsheet file in Microsoft Excel 7.0.

The tool uses safe macros that must be enabled for the tool to run properly. By default, Excel shows a dialogue box with the text, "The workbook you are opening contains macros. Some macros may contain viruses that could be harmful to your computer..." whenever it encounters a file with macros to warn users of potential viruses. If this message box is displayed when opening the tool, choose **Enable Macros**, which allows the built-in functions to operate. (If the user does not want to see the dialogue box, he/she can disable this prompt by going to the Tools menu, then selecting Options, selecting the General tab, and removing the check from the Macro Virus Protection check box.)

When the tool is successfully opened, an introductory form, as is shown in Exhibit A.1, is displayed. Clicking the "OK" command box closes this form, and allows the "Main Menu" worksheet to be displayed and accessed.

Exhibit A.1:
Introductory Form


UserForm2
Tool for
EVALUATING
NEIGHBOURHOOD
SUSTAINABILITY
This tool helps evaluate the sustainability of neighbourhoods in terms of auto and transit use and resulting greenhouse gas emissions.
The calculated results are based on regression models calibrated to data describing neighbourhoods in the Toronto Census Metropolitan Area in 1996.
IBI GROUP
OK

A.3 Main Menu Worksheet

The Main Menu Worksheet is shown in Exhibit A.2. It includes a scenario manager and six command buttons to access other tool options. All command buttons can be activated either by clicking on them with the mouse or by pressing <Alt> and the "accelerator key" for the button, which is the underlined letter on the button caption.

A.3.1 Scenario Manager

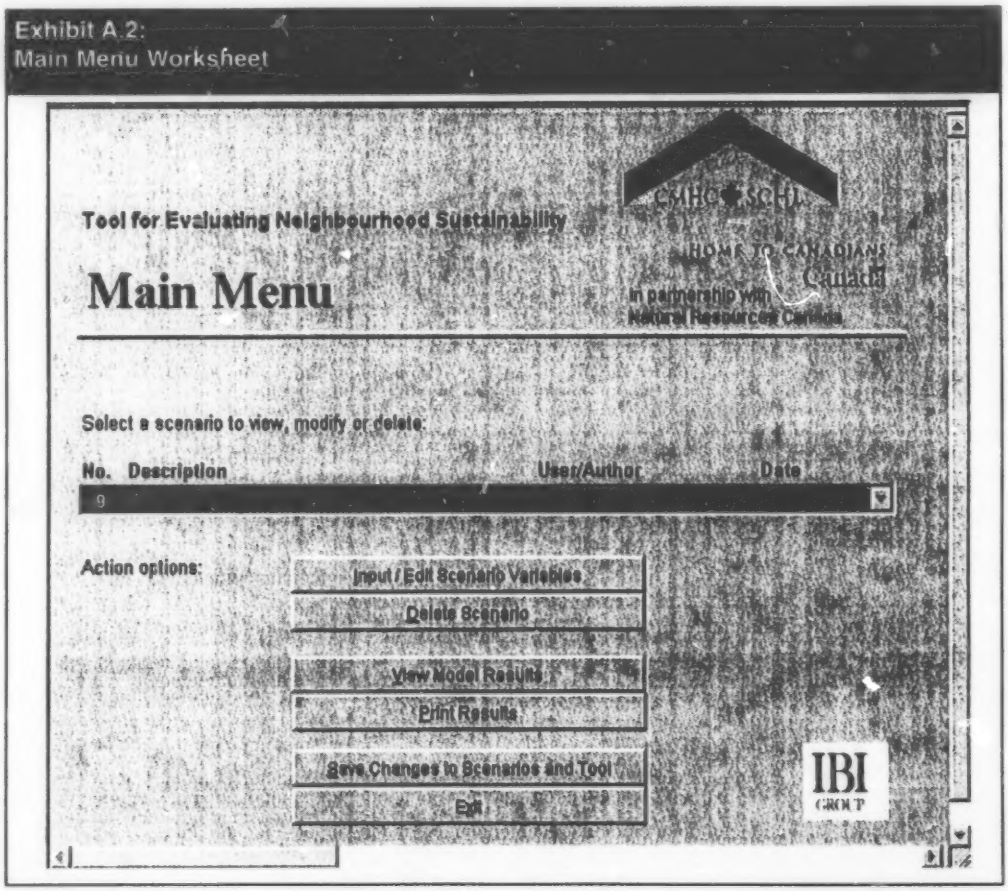
The spreadsheet tool allows the user to input neighbourhood scenarios and evaluate their greenhouse gas impacts. The scenario manager allows various neighbourhood scenarios to be saved within the tool. Scenario 0 has no pre-entered data on neighbourhood variables (i.e. it is a blank slate). The neighbourhood scenarios developed by the user can be compared with the nine pre-entered neighbourhood scenarios of the main report, which are saved as nine demonstration scenarios with the tool. Except for these demonstration scenarios, neighbourhood scenarios can also be modified or deleted. Theoretically, the limit to the number of scenarios that can be saved is the number of rows on a spreadsheet worksheet: 65,500.

The drop-down box on the Main Menu worksheet allows the user to choose an existing scenario, or to start a new scenario.

The first two command buttons below the scenario selection drop box are as follows:

- **Input/Edit Scenario Variables**- This calls up an input form that allows the user to input or change the values of the variables defining the neighbourhood.

Exhibit A.2:
Main Menu Worksheet



- **Delete Scenario**- This command button deletes the scenario shown in the scenario selection drop box. If the currently selected scenario is a demonstration scenario, a message box is shown saying the scenario cannot be deleted. Otherwise, a verification message box is shown asking whether the user is sure that the current scenario should be deleted.

Further options for creating or editing scenarios are included on the Neighbourhood Variables Input Form, discussed in Section A.4.

A.3.2 Other Command Buttons

The four other command buttons on the Main Menu worksheet have the following functions:

- **View Model Results**- Activating this command button makes the model results worksheet visible. This is where the estimated annual per household greenhouse gas emissions can be seen. This worksheet is described further in Section A.5.

- **Print Results**- If the user does not wish to view the model results before obtaining a hard copy, this button can be pressed to print the results directly.

- **Save Changes to Scenarios and Tool**- This saves changes to the tool, including the scenario selection and any new scenarios or modifications to the scenarios. The tool must be saved to retain any such changes to the tool.

- **Exit**- This button allows you to exit the program. If changes have been made to the tool since the last time it was saved, a message box will display asking whether the user would like to save the changes before exiting.

A.4 Neighbourhood Variables Input Form

The input form, accessed by choosing the first command button on the Main Menu Worksheet, is shown as Exhibit A.3. This form is used to input values of the neighbourhood design, socio-economic and location variables. It is also used to change the values of the explanatory variables in existing neighbourhood scenarios, and to save the scenarios and the tool.

The form has a number of text boxes into which the user enters the values of the explanatory variables that define a neighbourhood. There are also command buttons to help calculate some of the variables, as well as to activate other functions. These are described in detail below.

A red question mark in the vicinity of a variable indicates that there is a note to the user regarding that variable, such as typical values for that variable in the Greater Toronto Area, or tips on how to calculate the variable. Putting the mouse pointer over the red question mark activates a pop-up box displaying the help message.

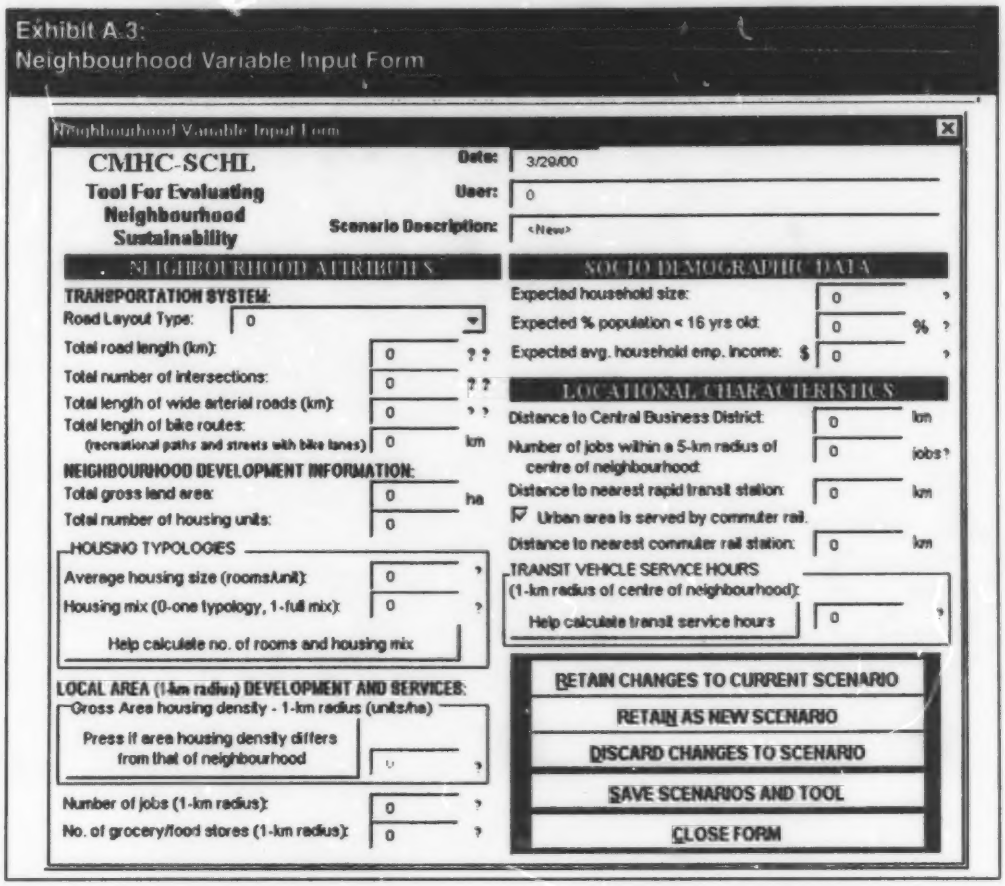
The following describes the variables specified using the input form:

Scenario Description

- **Date**- For new scenarios (created from Scenario 0, which has no pre-entered values), this will automatically be filled in as the current date, as read from the computer's internal calendar when the form is opened.

- **User name and Scenario description**- These are provided to help a user keep track of the neighbourhood scenarios evaluated

Exhibit A-3:
Neighbourhood Variable Input Form


Neighbourhood Variable Input Form
CMHC-SCHL
Tool For Evaluating Neighbourhood Sustainability
Date: 3/29/00
User: 0
Scenario Description: <New>
NEIGHBOURHOOD ATTRIBUTES
TRANSPORTATION SYSTEM:
Road Layout Type: 0
Total road length (km): 0
Total number of intersections: 0
Total length of wide arterial roads (km): 0
Total length of bike routes: (recreational paths and streets with bike lanes) 0 km
NEIGHBOURHOOD DEVELOPMENT INFORMATION:
Total gross land area: 0 ha
Total number of housing units: 0
HOUSING TYPOLOGIES
Average housing size (rooms/unit): 0
Housing mix (0-one typology, 1-full mix): 0
Help calculate no. of rooms and housing mix
LOCAL AREA (1-km radius) DEVELOPMENT AND SERVICES:
Gross Area housing density - 1-km radius (units/ha)
Press if area housing density differs from that of neighbourhood
Number of jobs (1-km radius): 0
No. of grocery/food stores (1-km radius): 0
SOCIO DEMOGRAPHIC DATA
Expected household size: 0
Expected % population < 16 yrs old: 0 %
Expected avg. household emp. income: $ 0
LOCATIONAL CHARACTERISTICS
Distance to Central Business District: 0 km
Number of jobs within a 5-km radius of centre of neighbourhood: 0 jobs
Distance to nearest rapid transit station: 0 km
Urban area is served by commuter rail.
Distance to nearest commuter rail station: 0 km
TRANSIT VEHICLE SERVICE HOURS (1-km radius of centre of neighbourhood):
Help calculate transit service hours 0
RETAIN CHANGES TO CURRENT SCENARIO
RETAIN AS NEW SCENARIO
DISCARD CHANGES TO SCENARIO
SAVE SCENARIOS AND TOOL
CLOSE FORM

Neighbourhood Attributes

- **Road layout type-** To see all layout types, left-click the mouse button over the arrow at the right of the drop box. The seven possible road layout types are as follows:

  1- Strict rectangular grid, which describes neighbourhoods containing exclusively urban grid networks, typical of pre-1950's development;

  2- Industrial grid, describing areas with fairly widely spaced roads passing through primarily industrial areas;

  3- Primarily rectangular grid, consisting of grid networks with some diagonal breaks;

  4- Mix of rectangular and curvilinear, used to describe neighbourhoods where there is a predominance of curvilinear streets intermixed with a grid network;

  5- Regular curvilinear, used to describe neighbourhoods consisting primarily of curved streets with at least some continuity between the streets;

  6- Random curvilinear, used to describe neighbourhoods with road layout patterns typical of post 1970's development consisting of a high proportion of streets ending with cul-de-sacs and butting onto large arterial roadways;

  7- Rural grid, used to describe zones in the outer areas that are largely undeveloped and consist of widely

spread regional arterials, township roads and rural highways.

- **Road length-** This includes all roads except for expressways. This should include all roads in the neighbourhood and half of the length of roads lying on the neighbourhood periphery.

- **Number of intersections-** This is the number of intersections connecting two or more roads in the neighbourhood. This should include all intersections in the neighbourhood and approximately half of the intersections on the neighbourhood periphery.

- **Total length of wide arterial roads-** This includes all roads, excluding expressways, that have three or more lanes per direction. This should include all wide arterial roads in the neighbourhood and half of the length of wide arterials lying on the neighbourhood periphery.

- **Total length of bike routes-** This includes streets with bike lanes, as well as off-street bike routes and park paths where bicycling is allowed.

- **Total gross land area-** This is the total land area of the neighbourhood, including roads, parks, residential, and other land uses.

- **Number of housing units-** This is the total number of housing units in the neighbourhood. For townhouses, semi-detached units, duplexes and apartments, include all the housing units in the building.

- **Housing Typologies-** This includes two variables: the mix of housing typologies in the neighbourhood, and the average size of the housing units in terms of the number of rooms. This includes all rooms, not just bedrooms. Refer to Chapter 3 of the report for a description of how this variable is calculated. The tool will calculate the housing types mix and the average number of rooms through the use of the housing typologies form, accessible via the command button, "Help calculate no. of rooms and housing mix". On this form, the user indicates the percentage (0-100) of total housing units that are of one of five housing types, as well as the average number of rooms for that dwelling type. Clicking the "Cancel" button on this form closes the form and retains the current values of housing mix and average housing size. Clicking the "Done" button closes the form and automatically updates the values of these two variables. After doing so, the values for the mix of housing typologies and the average size of housing units is automatically entered for you.

- **Gross Area housing density-** The model uses the density of housing within a 1-km radius of the neighbourhood centroid as a variable in the model. The density in the local area may differ from the neighbourhood density. For simplicity, by default the tool uses the same housing density as in the neighbourhood for the area. This value is calculated and displayed in the housing density box. To override this default value and enter a different value for housing density within a 1-km radius (if it is different from that of the neighbourhood), the toggle button, "Press if area housing density differs from that of neighbourhood" should be pressed. This allows the user to access the housing density variable and change its value manually to the local area (1-km radius) density. Pressing the button again returns the value to the default value based on the neighbourhood housing density.

- **Number of jobs (1-km radius)-** This is the total number of jobs from all types of employment within a 1-km radius of the centre of the neighbourhood.

- **Number of grocery/food stores (1-km radius)-** This is the number of grocery stores within a 1-km radius of the centre of the neighbourhood, regardless of the store sizes. The model includes all stores that were listed in the Yellow Pages under Grocers-Retail. Because this variable acts as an index

of total shopping opportunities, the variable works best if grocery-shopping opportunities are distributed the same as other retail opportunities. If the retail make-up of the area has a high proportion of grocery stores, the user may wish to reduce the value of the variable accordingly. Conversely, if there are very few grocery stores in spite of a large amount of retail, the user may wish to increase the value of the variable slightly.

Socio-Demographic Data

- **Expected household size-** This is the average number of people expected to live in each housing unit in the neighbourhood.

- **Expected % population < 16 years old-** This number, entered as a percentage (0-100), indicates how much of the total population is under sixteen years old.

- **Expected avg. household employment income-** The model was developed based on average household employment income, which may be up to 20% less than a household's total income. The model also uses the average employment income of individual workers as an explanatory variable. To simplify the tool, the user only enters average household income. A reasonable estimate of individual employment income is then calculated by the tool by dividing the household employment income by 1.5, which is the average number of workers per household in the Toronto CMA.

Locational Characteristics

- **Distance to CBD-** This is the distance in km to the Central Business District. In developing the model, which is based on Toronto data, the corner of King Street and Bay Street in Toronto was used as the centre of the CBD.

- **Number of jobs within a 5-km radius of the centre of the neighbourhood-** This is the total number of jobs within a 5-km radius of the centre of the neighbourhood.

- **Distance to nearest rapid transit station-** This is the distance to the nearest rapid transit station (e.g. subways and Light Rapid Transit), excluding commuter rail stations (e.g. GO Transit in the Greater Toronto Area).

- **Distance to nearest commuter rail station-** This is the distance in km to the nearest commuter rail station (e.g. GO Transit in Toronto, BC Transit Commuter Rail in Vancouver, and AMT Commuter Rail in Montreal). If the neighbourhood is located in an urban area that has no commuter rail service, the check box indicating this should be blank. Only when the check box is checked is the text box accessible for modification; otherwise, the value displayed in it is zero.

- **Transit vehicle service hours-** This is the sum of the total time on a typical weekday that buses spend passing through an area defined by a circle of 1-km radius centred on the neighbourhood centroid. The measure is a function of the frequency of bus service and of the extent of bus route coverage in the area. This may be a difficult measure to calculate; therefore, an optional form can be activated by pressing the command button "Help calculate transit service hours," which calculates the variable automatically. The information entered in this form is not saved with the scenario, but will remain in the form for use in another scenario if the values are not reset to zero. (Alternatively, typical values of bus vehicle service hours in the user help note can be used to estimate this variable. This can be accessed by passing the cursor over the red question mark.)

The spreadsheet tool will not prevent users from entering nonsensical data as input variables, such as negative percentage values or total housing unit percentages of more than 100%. In some such cases there may be an error in the model calculations that will prevent the model from providing a numerical result. The onus is on the user to input realistic data.

In addition, there are five command buttons with the following actions:

- **Retain changes to current scenario-** This retains the modifications to the current scenario, such that after working on another scenario and the same scenario was selected again in the future, it would contain these modifications. Otherwise, the changes would remain only until another scenario is selected.

- **Retain as new scenario-** This retains the modified scenario as a new scenario, which then becomes the current scenario. The previous scenario, on which this new scenario is based, is retained in its last saved form, without the new modifications.

- **Discard changes to scenario-** This changes the scenario variables back to the values it had at the last time the scenario changes were retained.

- **Save scenarios and tool-** The above two commands change, create or delete scenarios. These changes will remain active during a session of using the tool, that is, while the tool is not closed. However, the tool must be saved to keep these changes when the tool is later reopened. The "Save scenarios and tool" command saves these changes. Pressing this command is the same as saving the spreadsheet tool with its current file name.

- **Close form-** This closes the form without carrying out any of the above actions. Although changes to the current scenario will be included in the model results, these changes will not be saved with the scenario if it is re-selected later.

A.4 Model Results Worksheet

The results worksheet is shown as Exhibit A.4. This is the sheet that shows the annual household greenhouse gas emissions. This worksheet is accessed via the command button on the Main Menu worksheet, "View Model Results." The sheet has five parts:

- **Worksheet header-** This includes two command buttons allowing the user to return to the Main Menu worksheet or to print the results for the current scenario. This header remains visible even when the user uses the vertical scroll bar to see the remainder of the worksheet.

- **Scenario description-** This includes the descriptive information included with the scenario to keep track of the scenario results.

- **Summary of neighbourhood variables-** This shows the values of the explanatory variables defining the scenario, as input by the user.

- **Model parameters-** This summarizes the model parameters and the values of the variables as used by the model.

- **Neighbourhood performance-** This summarizes the performance of the neighbourhood in terms of weekday travel per household and annual greenhouse gas emissions per household, expressed as CO_2 equivalents. A small chart shows the greenhouse gas emissions by auto and transit modes, and changes colour from green to black to red with increasing emissions levels. Pressing the command button below this section displays a table of the results from the nine demonstration scenarios, thus providing a quick reference for comparison with the current scenario's results.

Exhibit A.4:
Model Results Worksheet

Print Results | Return to Main Menu

CMHC ◆ SCHL

In partnership with
Natural Resources Canada

Tool for Evaluating Neighbourhood Sustainability
Summary of Model Input and Results

Date: n/a
User/Author: <demonstration>
Scenario Description: 1A - Inner Area, Suburban-Type Development

SUMMARY OF NEIGHBOURHOOD DESCRIPTIVE VARIABLES

Neighbourhood Attributes

Road layout type:	Random Curvilinear	Number of housing units:	165
Total length of non-expressway roads (km):	4	Average housing unit size:	9
Total number of intersections:	12.0	Housing Mix:	0.00
Total length of wide arterial roads (km):	0.8	Area housing density (1-km radius) (units/ha):	3.67
Total length of bike routes (km):	0.0	Number of Jobs (1-km radius):	0
Daily bus VSH (1-km r.):	35.0	Number of grocery/food stores (1-km radius):	0
Land area (ha):	45.0		

Socio-Demographic Data

Expected avg. persons/hh:	2.79
Expected % population < 16 yrs old (%):	21.0
Expected avg. household income:	$51,430

Locational Characteristics

Distance to CBD (km):	5.0
No. of jobs (5-km radius):	400,000
Distance to nearest rapid transit station (km):	1.0
Urban area is served by commuter rail:	TRUE
Distance to nearest commuter rail station (km)	5.0

MODEL PARAMETERS

Model of Weekday Auto VKT

	Value	Coefficient
Constant:		34.5
Distance to CBD (km):	5.0	0.680
Vehicles/Household **(estimated via regression model)**:	1.52	15.1
Ln(Jobs, 5-km radius):	12.9	-3.60
Land-use mix (entropy):	0.00	-8.73
Ln(persons/household):	1.03	17.5
Minimum distance to rapid transit/commuter rail station (km):	1.0	0.534
Personal income ($1000s)	34.3	0.228
Road type is rural grid:	0	5.507
Ratio of arterial roads to total non-expressway roads:	20%	12.968
Intersections/road-km:	3.0	-1.14
Under-reporting correction factor:		*1.47*
Average VKT generated/household:		**58.5**

Model of Weekday Transit PKT

	Value	Coefficient
Constant:		-7.03
Distance to CBD (km):	5.0	0.182
[Distance to CBD (km)]^2:	25.0	-0.00294
Predicted vehicles/ household:	1.52	-2.84
Transit VSH (1-km radius):	35.0	0.0769
Ln(housing units, 1-km radius):	7.05	0.870
Average persons/household:	2.79	5.47
Ln(Jobs, 1-km radius):	0.00	-0.496
No. of stores (1 km radius):	0	-0.165
Bike route in neighbourhood (binary):	0	0.642
Rapid transit station within 1 km (binary) * Distance to CBD (km):	5.0	0.243
Commuter rail station within 2 km (binary) * Distance to CBD (km)	0.0	0.0233
Under-reporting correction factor:		*1.30*
Average PKT generated/household:		**19.3**

NEIGHBOURHOOD PERFORMANCE

Weekday household travel behaviour:

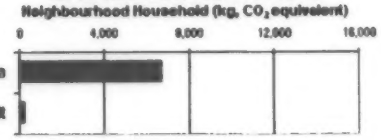
Auto VKT	58.5 VKT/hh
Transit PKT	19.3 PKT/hh

Annual household vehicle emissions:

Auto	6,700	kg CO_2 equivalent
Transit	260	kg CO_2 equivalent
TOTAL	7,000	kg CO_2 equivalent

Number of households: 165

Annual GHG Emissions from Travel Per Neighbourhood Household (kg, CO_2 equivalent)



Compare with other neighbourhood scenarios

IBI